Rethinking Clutter Filtering and Improving Signal Statistics

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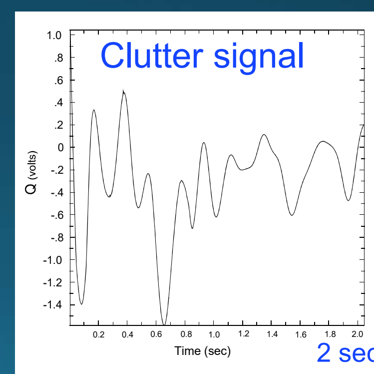


NEXRAD TAC Meeting
Norman OK
29 April 2019

Spectra-Based Clutter filtering

- Since the advent of fast digital receivers this has been the standard, e.g., GMAP
- Replaced time domain filters
- Very common in weather radars

Discrete Fourier Transform

- Use FFT algorithm
- *Turns a finite length time series into a periodic repeating function*
- What are the consequences of this???

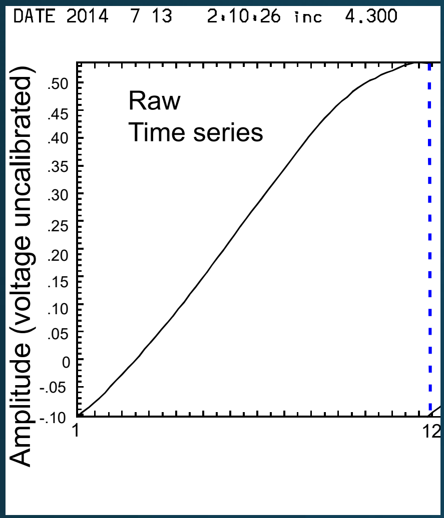
Fourier Transform pair

$$
\begin{aligned}
X(mF) &= \sum_n x(nT) e^{-j2\pi mnFT} \\
x(nT) &= \frac{1}{N} \sum_m X(mF) e^{j2\pi mnFT}
\end{aligned}
$$

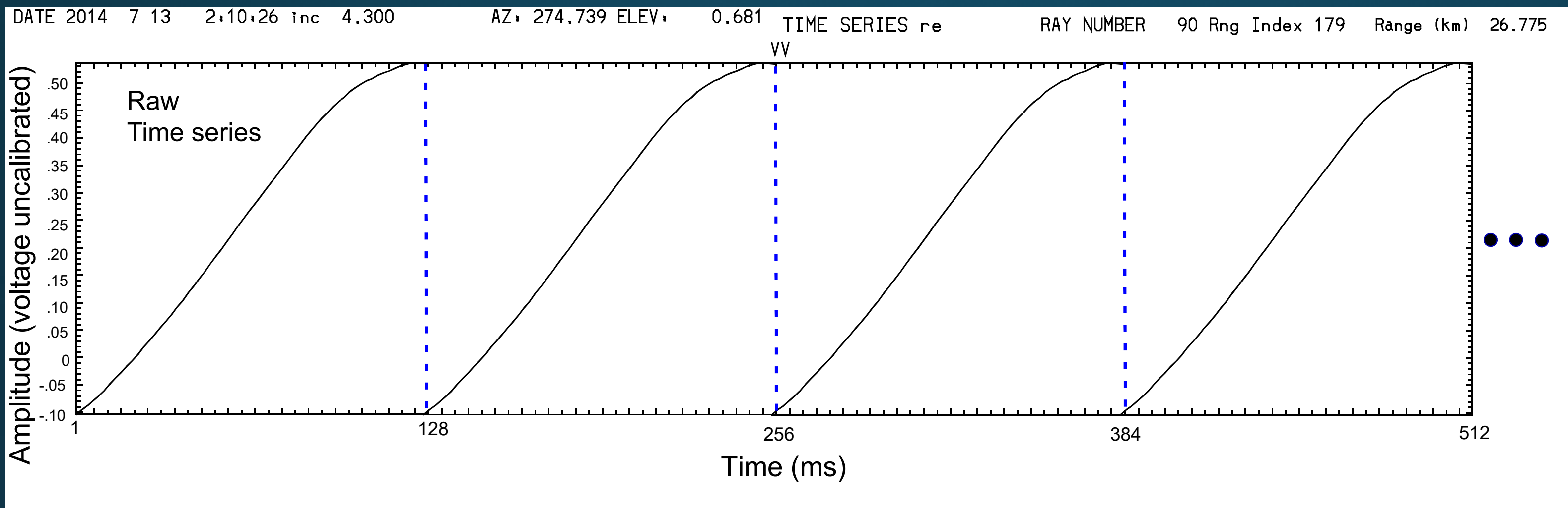
Frequency domain

Time domain,
i.e., sum of sinusoids

Real Part of a S-Pol Time Series.



Real Part of a S-Pol Time Series. DFT creates a periodic signal



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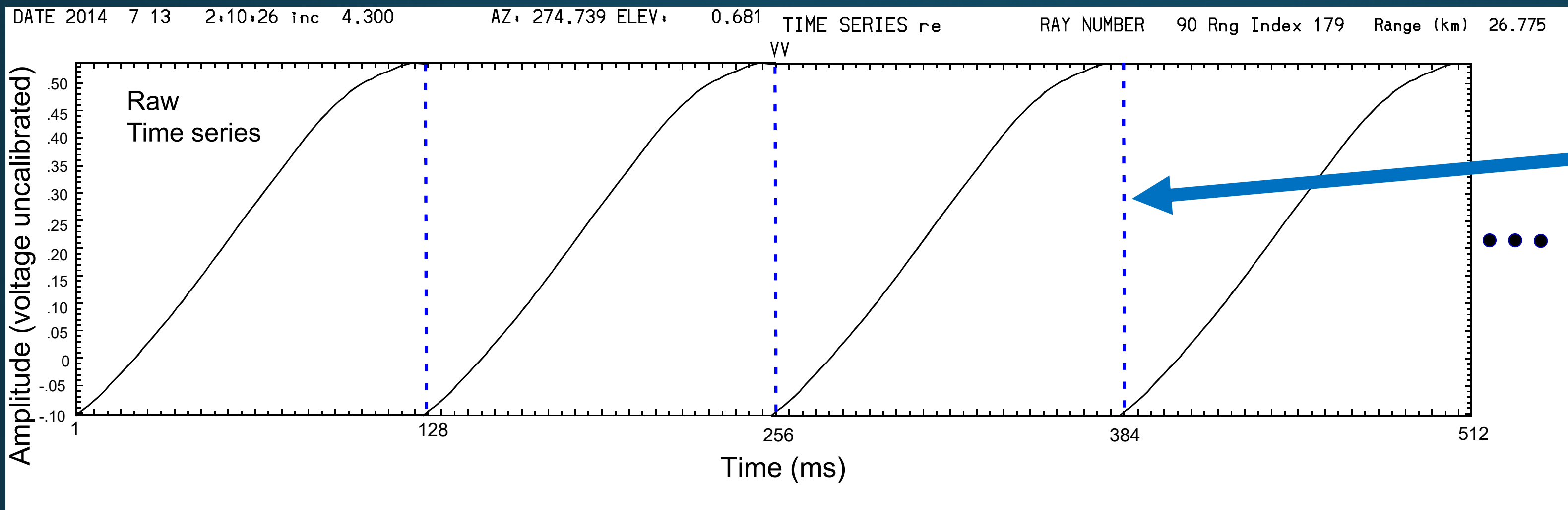
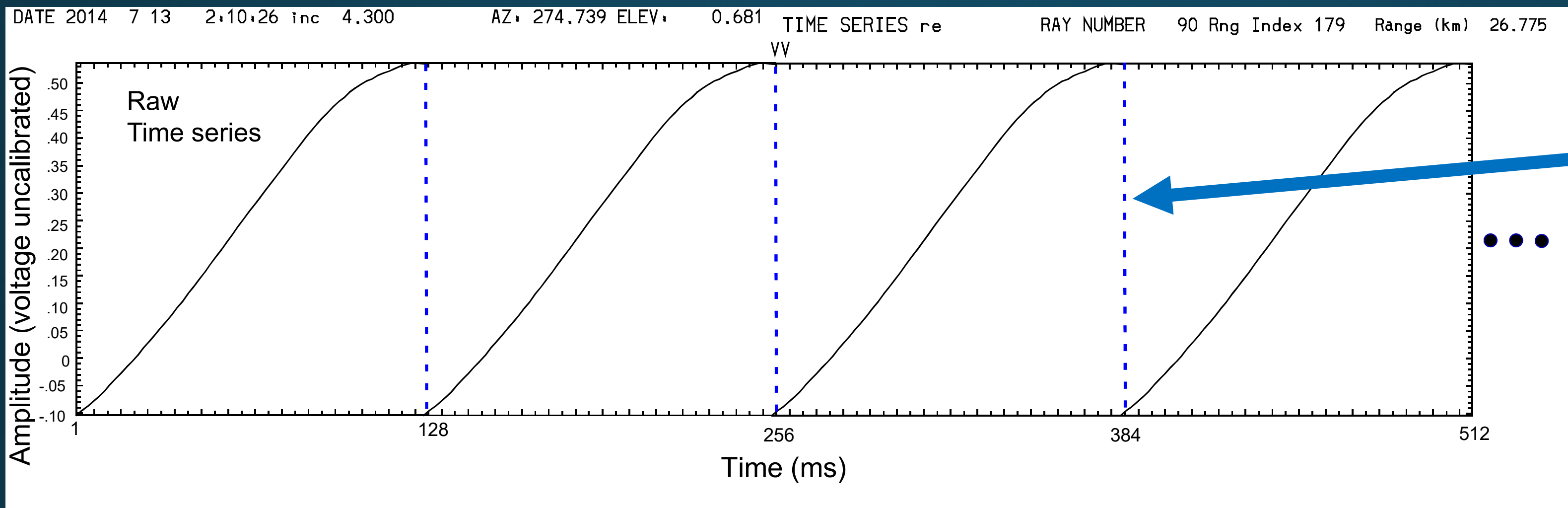


In order to create a sum of sinusoids that can replicate this jump discontinuity, many higher frequency sinusoids are required.

Real Part of a S-Pol Time Series. DFT creates a periodic signal



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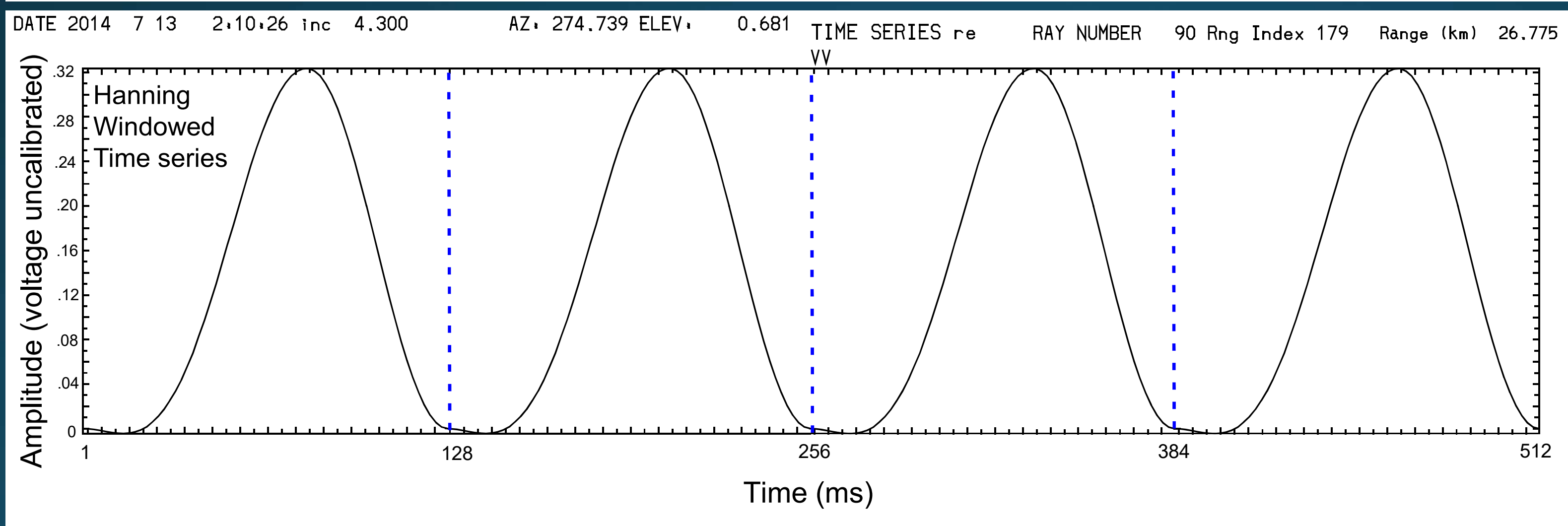
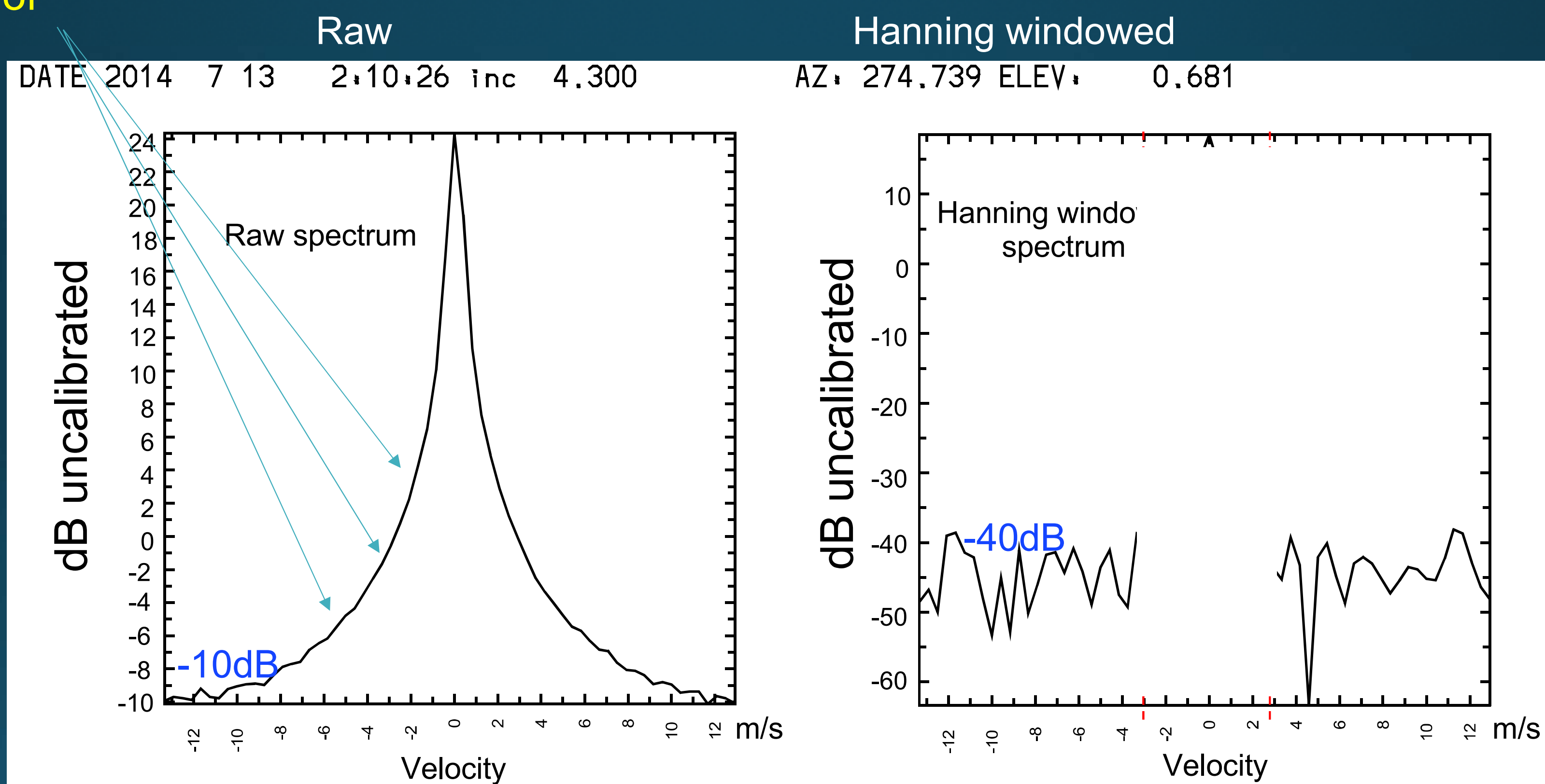


Hanning Windowed Time series

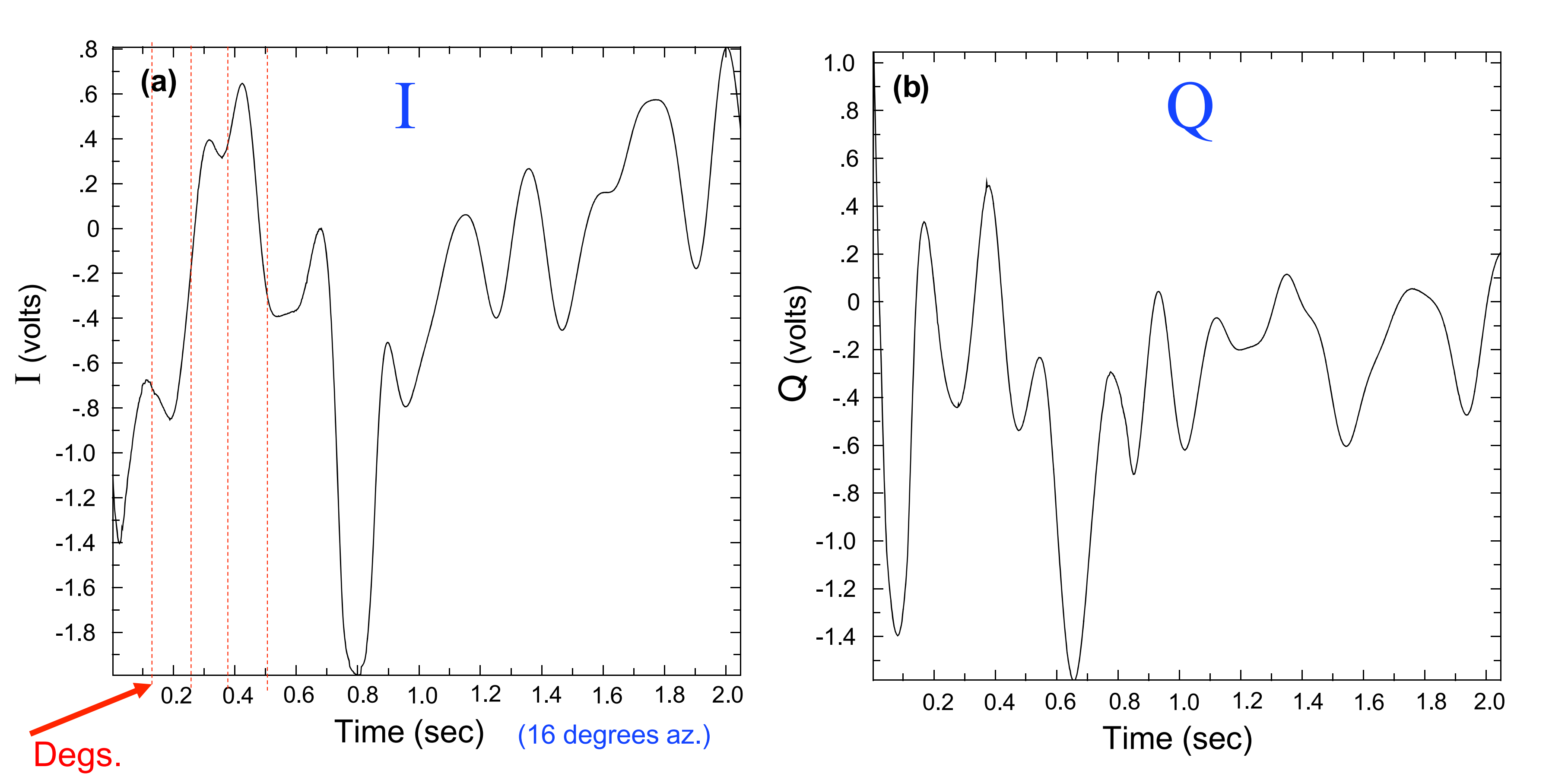
Window Effects on Spectra

The smooth curve spectrum is an artifact of the jump discontinuity

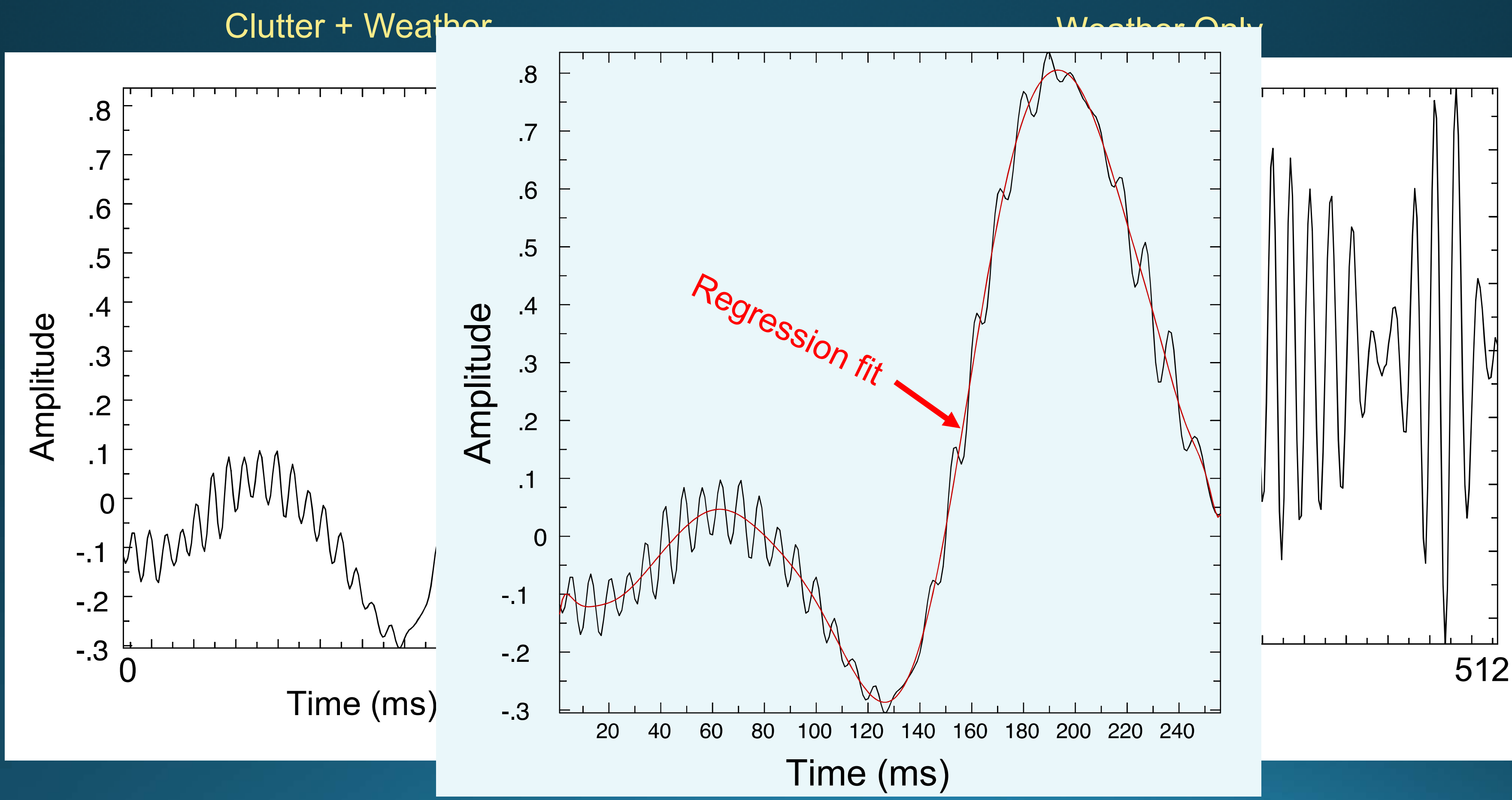


Typical Clutter I and Q Signals

Scan of Rocky Mountains by S-Pol at 8 deg/sec.

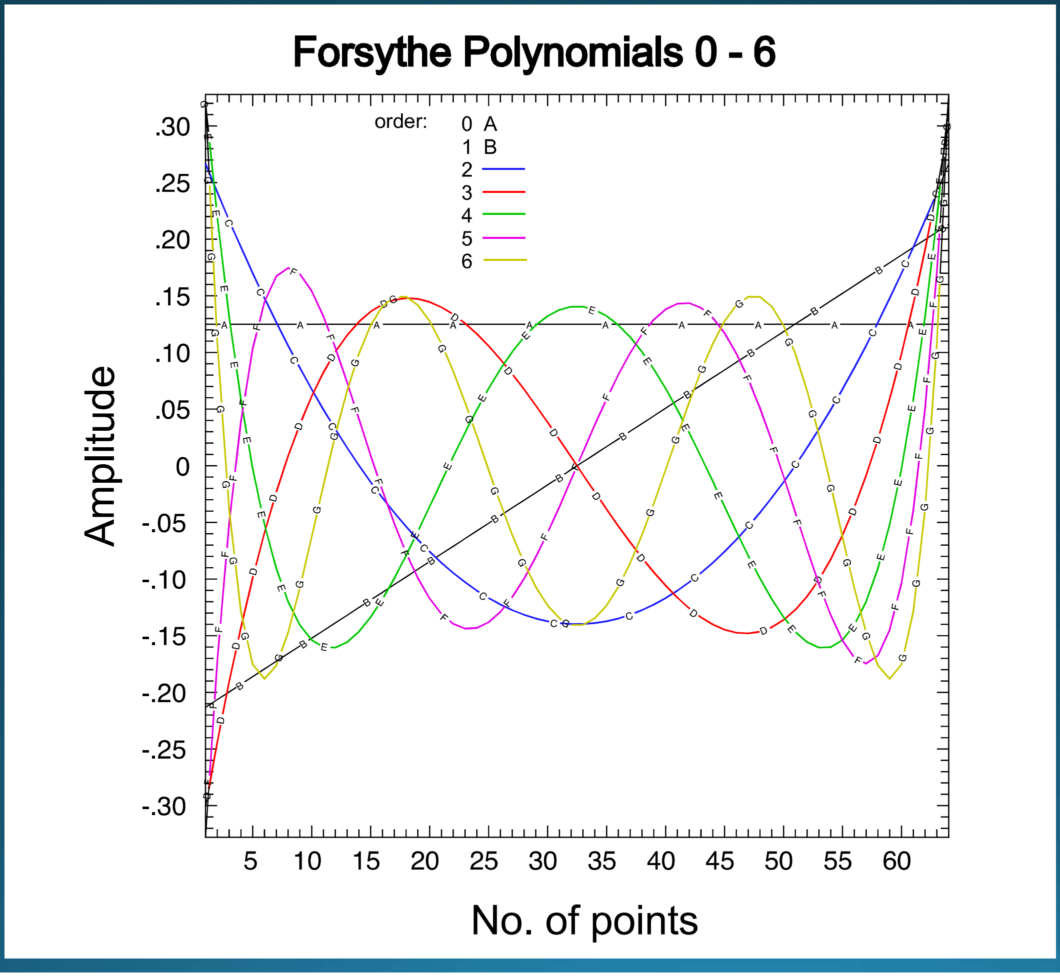


What is Regression Filtering?



Represent the I and Q Signals as a Sum of These Orthogonal Polynomials

Fast, low round off error algorithm: http://jean-pierre.moreau.pagesperso-orange.fr/



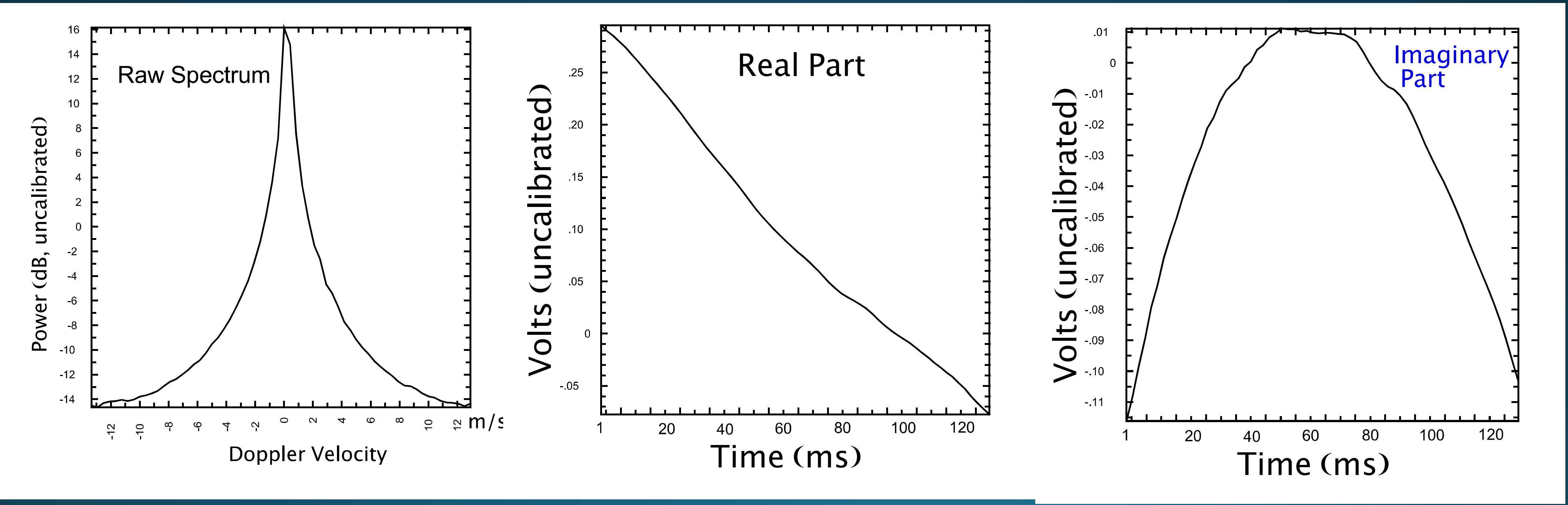
Regression Clutter filtering

- Regressions filters have a history in biomedical field
  - Kadi, A. P. and T. Loupas, 1995: On the performance of regression and step-initialized iir clutter filters for color Doppler systems in diagnostic medical ultrasound. *IEEE Trans. Ultrasonics, Ferroelectrics, and Frequency Control*
- And weather radar
  - Torres, S. and D. Zrnic´, 1999: Ground clutter canceling with a regression filter. *J. Atmos. Oceanic Technol.*

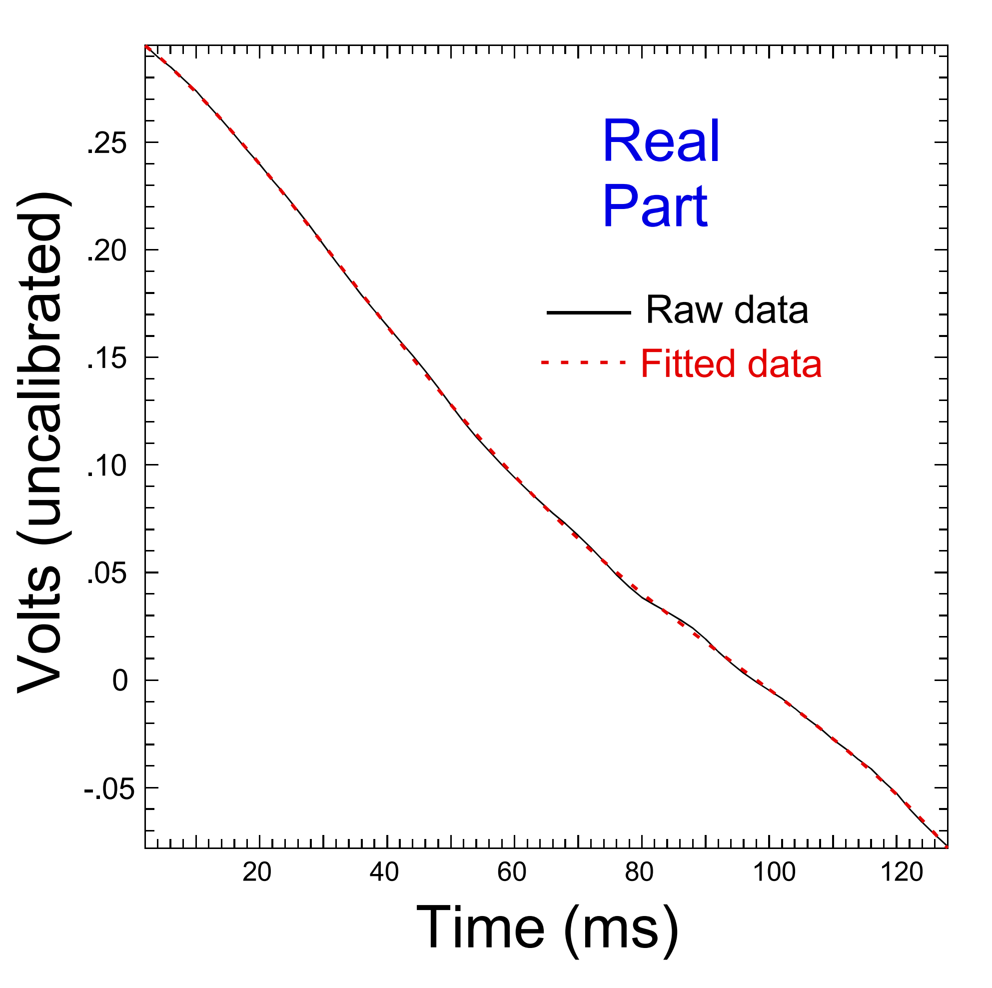
Regression Filter Example on S-Pol Data

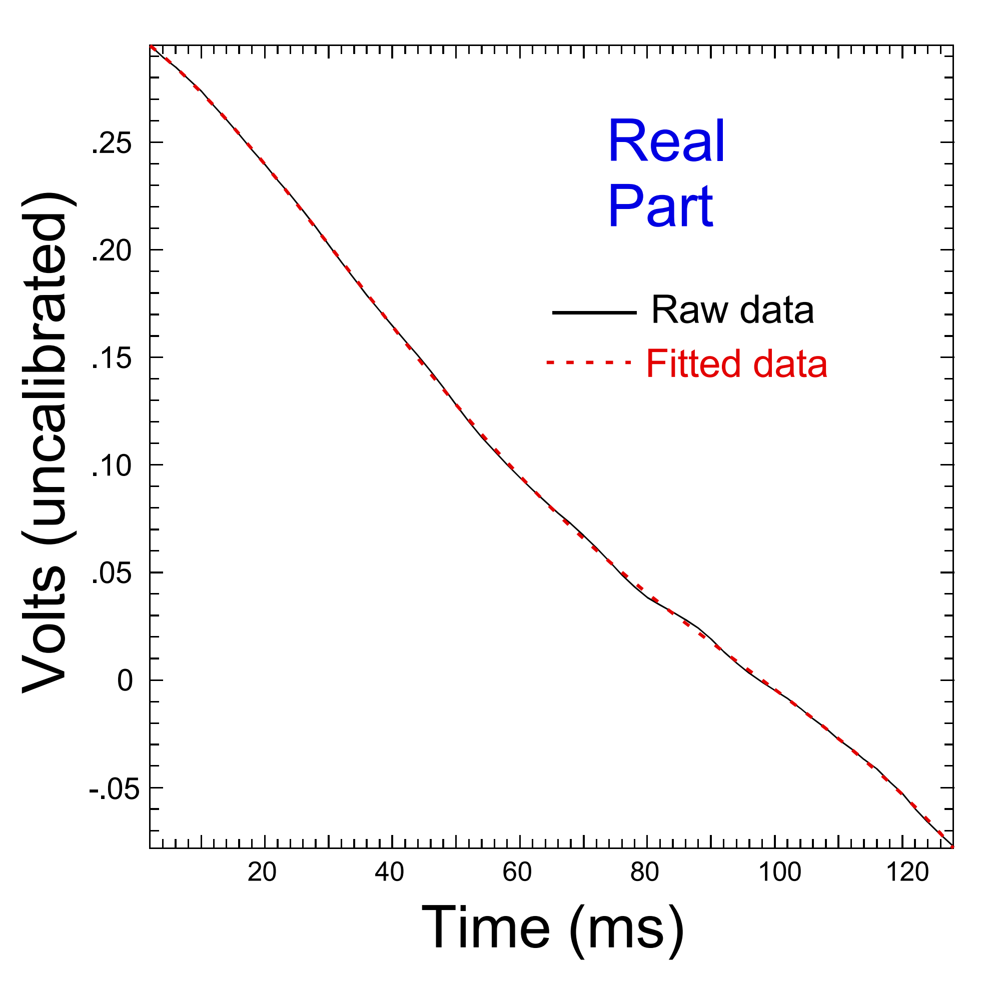
Power Spectrum

Time series

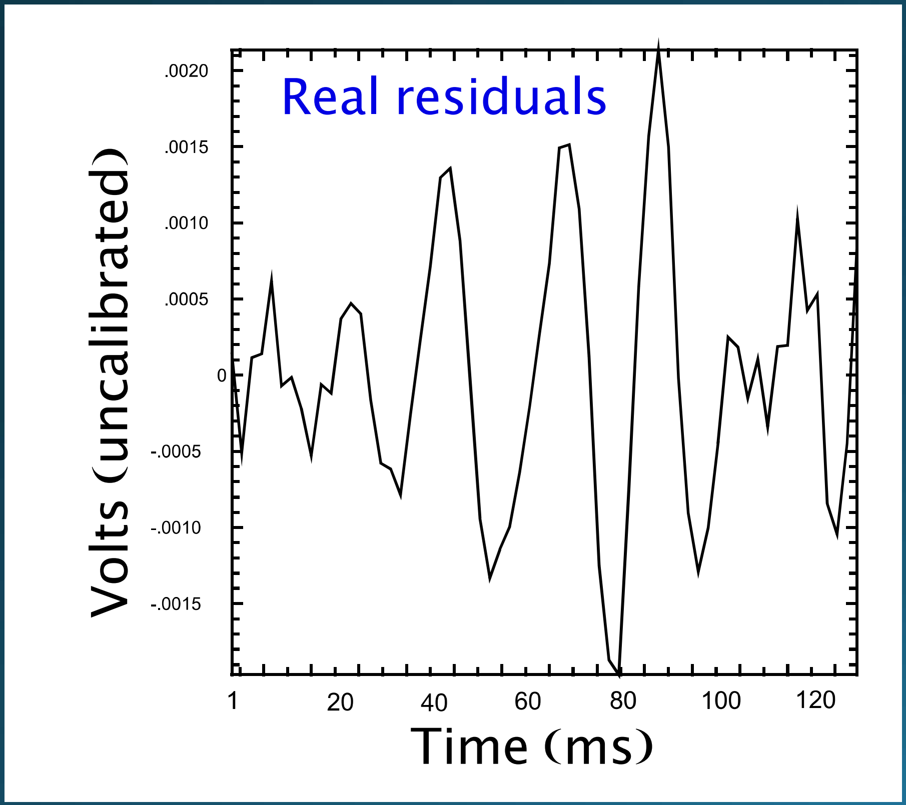


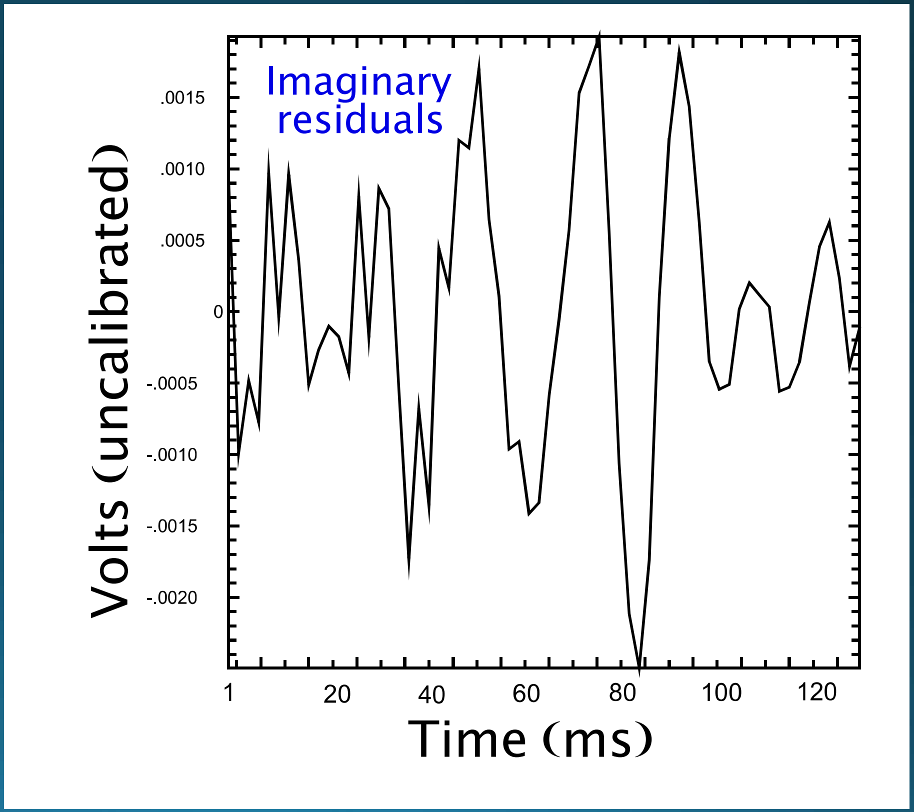
8th order polynomial fit



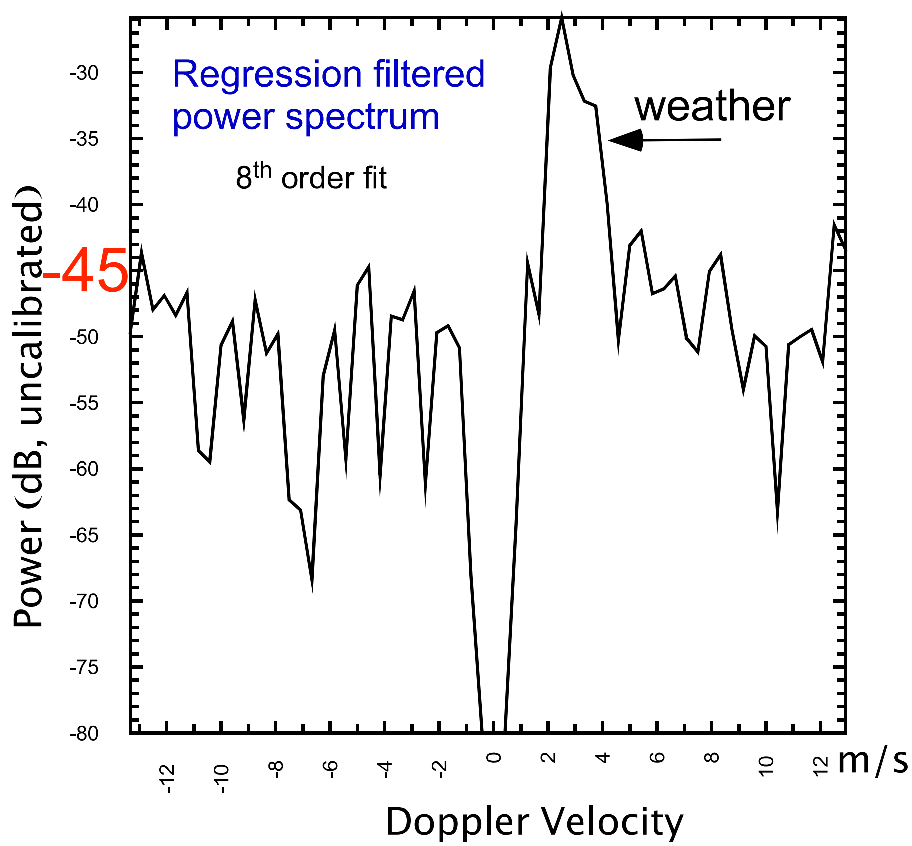


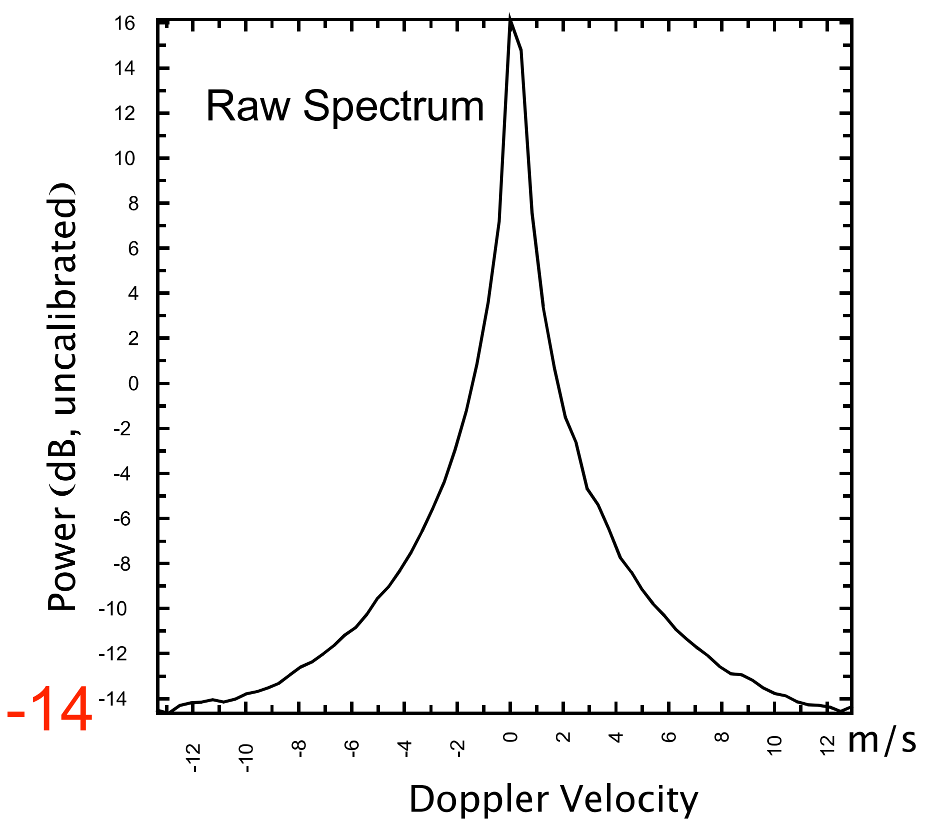
Subtracting the polynomial fit from the time series…..



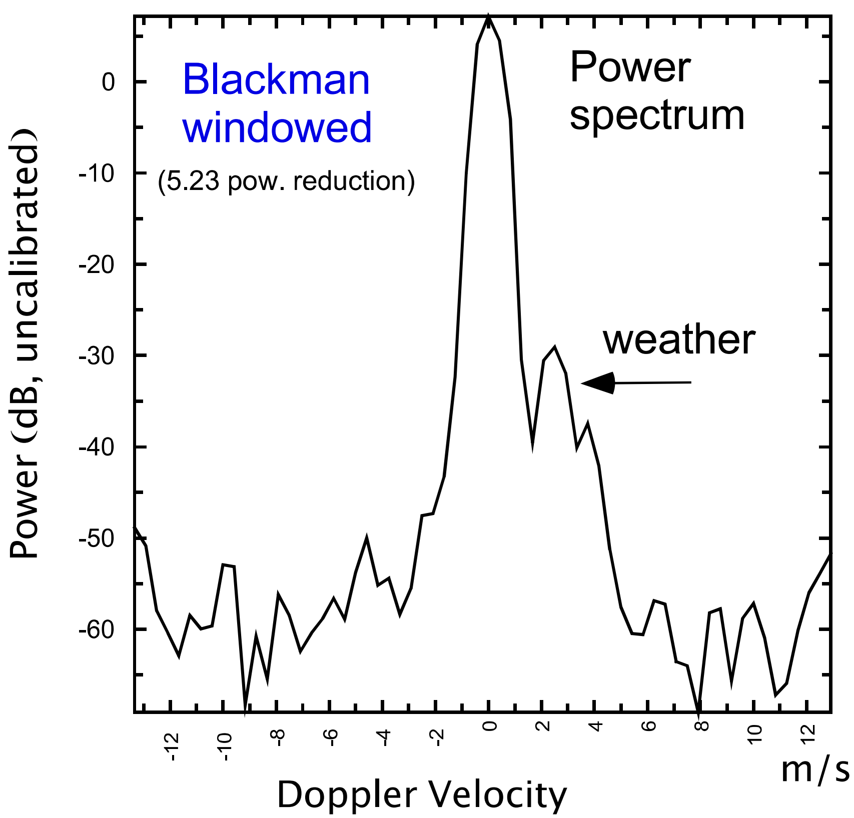


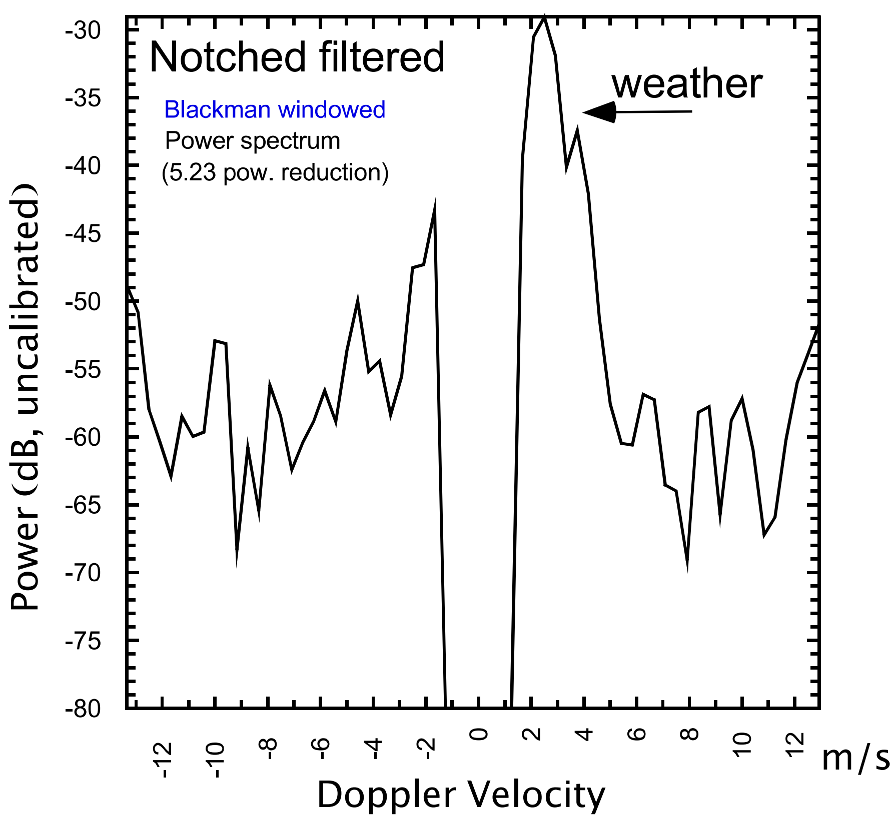
Regression Filtered versus Raw Spectrum





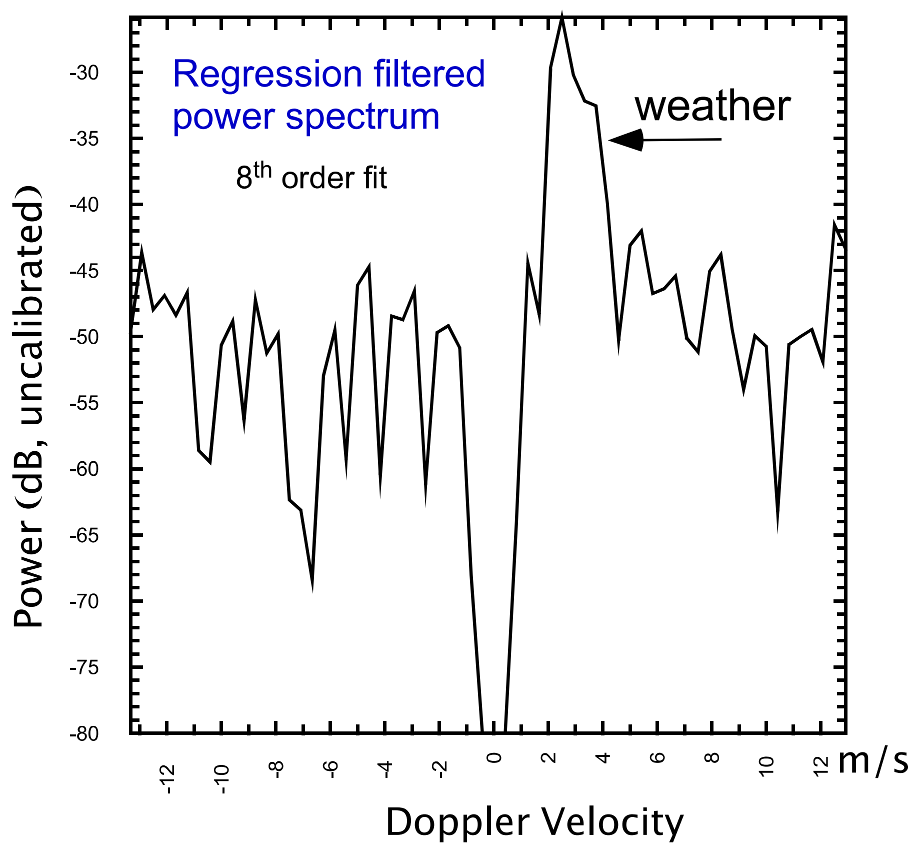
Blackman Window and Notch Technique



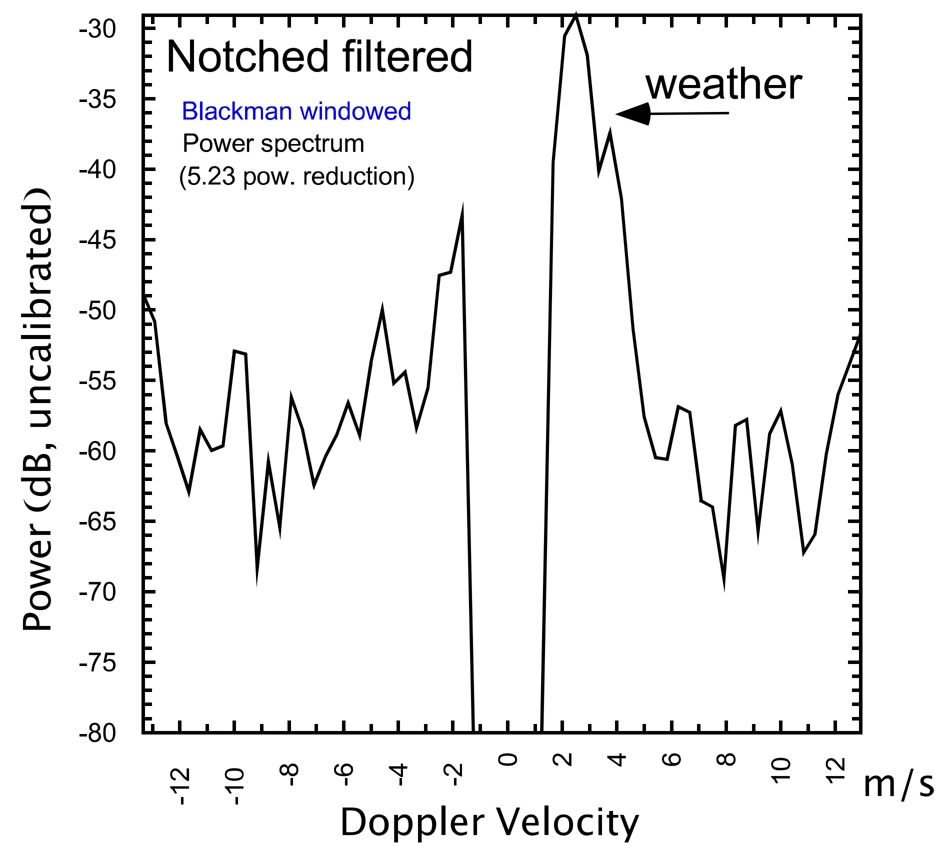


Comparison

Regression



Window and Notch



Regression versus Window and Notch

- Spectra seem similar! What’s the difference?
- WHY USE A REGRESSION FILTER???

Signal Statistics

- Blackman window: 5.23dB attenuation

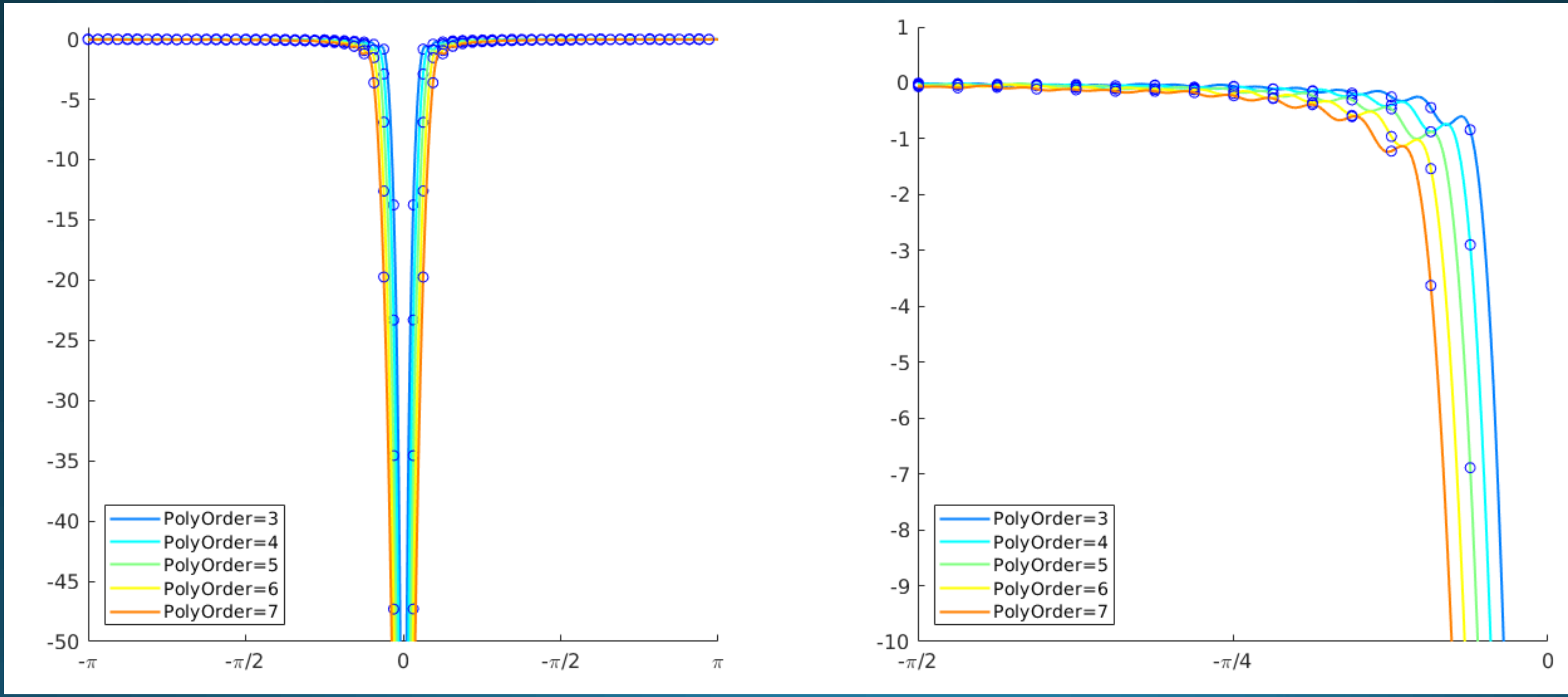
  About 50% increase in variance!

- Hanning window: 4.19 dB attenuation

  About 35% increase in variance!

Regression Frequency Response

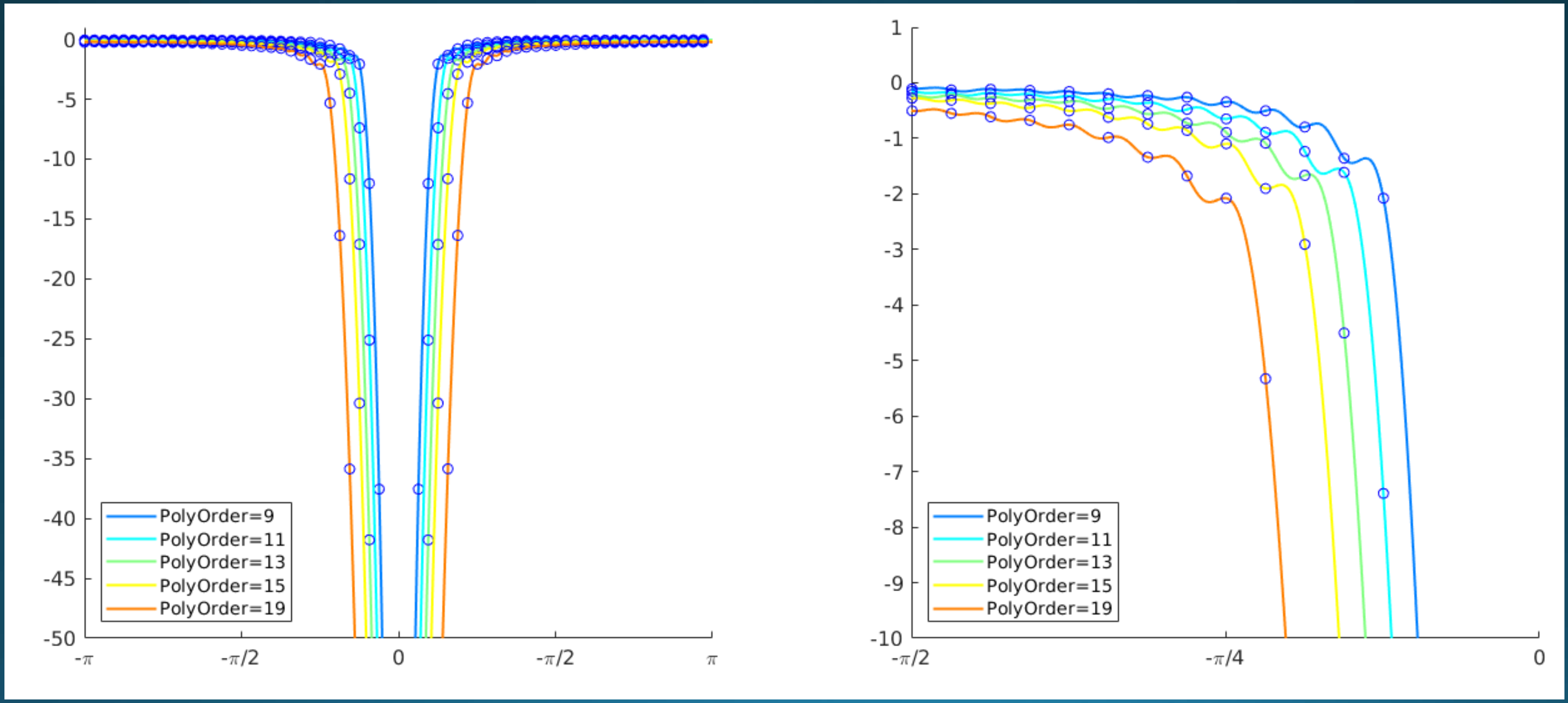
64 point time series for polynomial orders 3 - 7



Frequency Response 2

64 point time series for polynomial orders 9, 11, 13, 15, 19

Frequency response depends on sequence length and polynomial order



Modified Regression Filtering

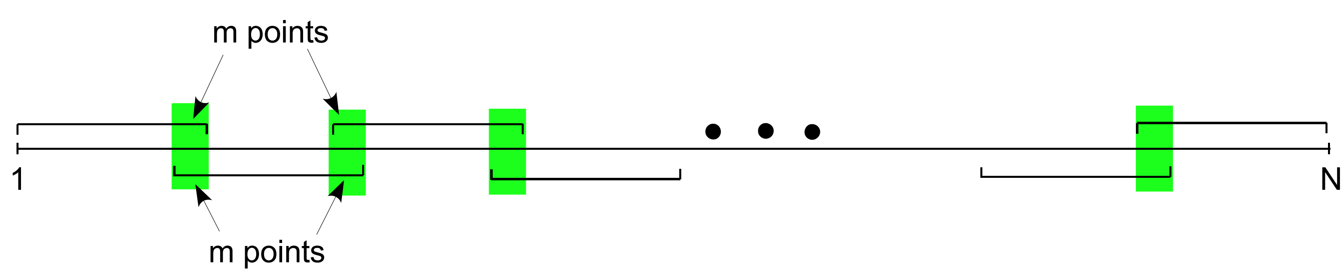
Standard technique: Take length N sequence, fit a polynomial to it and subtract to remove the low frequency clutter components.

Modified technique: Break the sequence into blocks, lets say 4 for this example:

1. Do 4 regression fits, thus suppressing the ground clutter in each block
2. Concatenate the blocks back into one sequence
3. Calculate radar variables

The Blocks Can Be Overlapped and Weighted

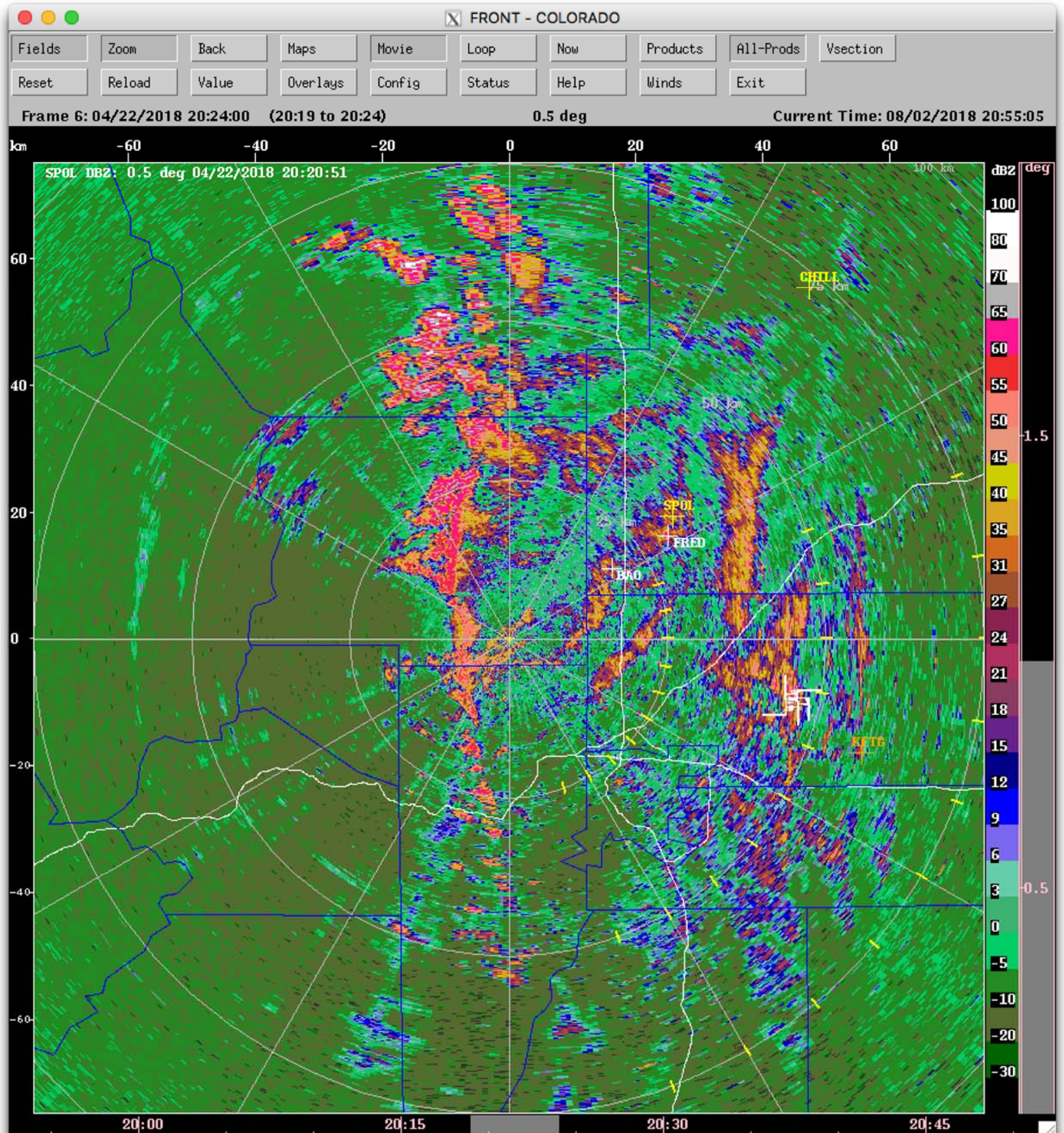
This is to reduce slight discontinuities at end points.



Length N sequence broken into overlapping blocks. The overlap is m points and these regions are shown in green.
After filtering, overlapping pairs of points are averaged so that a N point filtered sequences is created. This is done to smooth the transition from one block to the next.

S-Pol Clutter Environment at Marshall

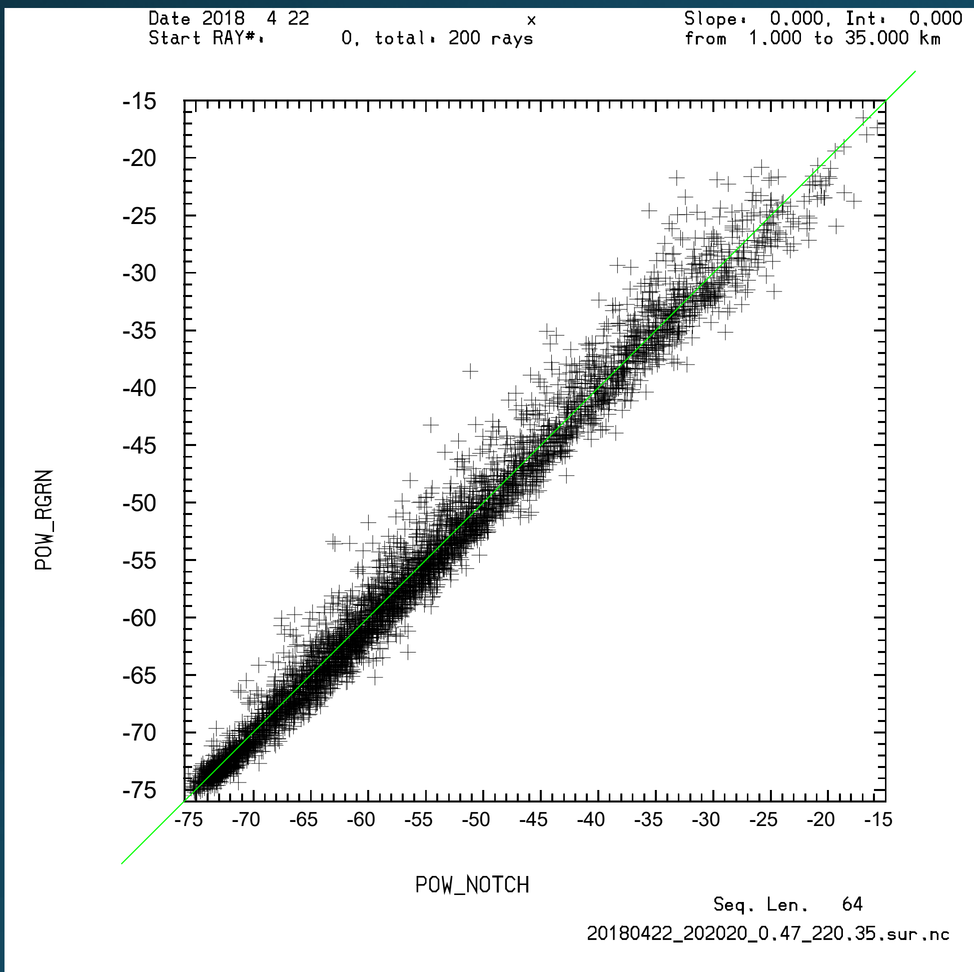
22 April 2018
0.5 elevation

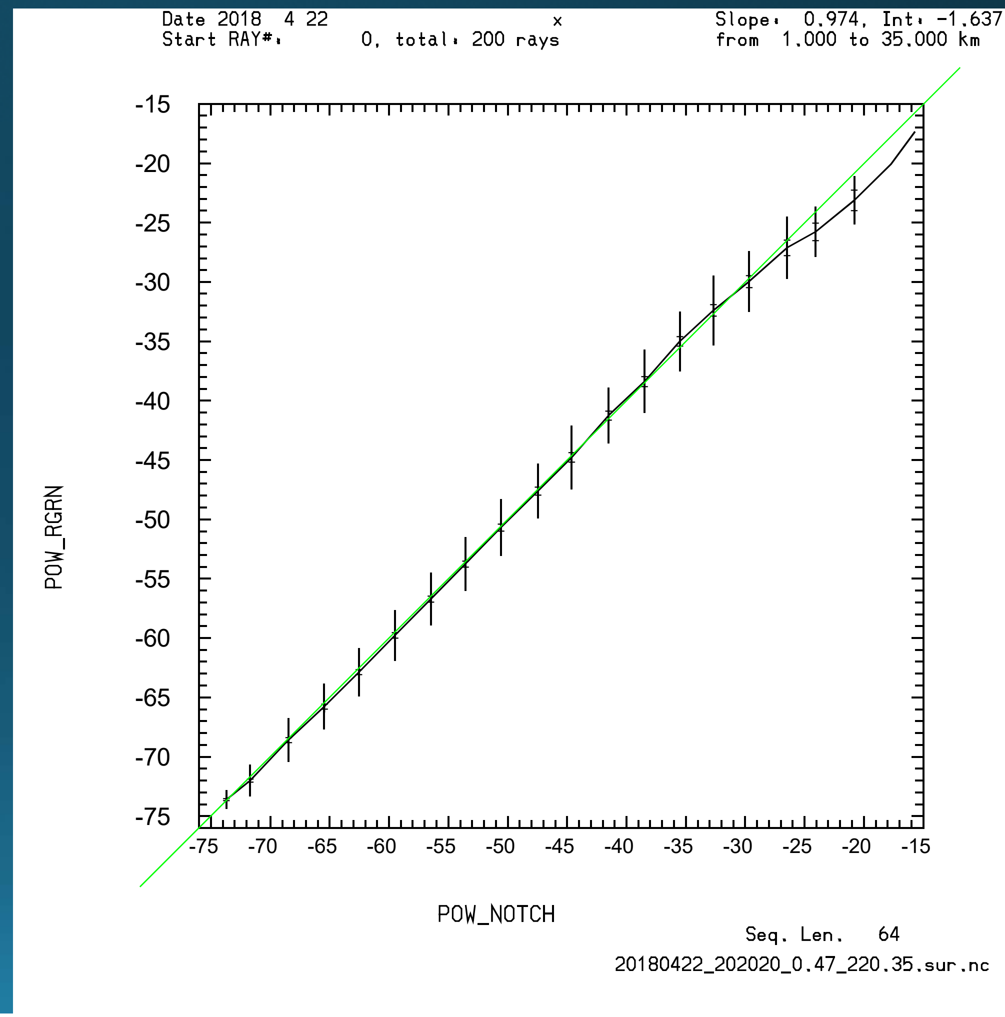


Compare Clutter Rejection of the Regression and GMAP like filters (notch width is constant)

Scatter Plots Regression vs Window and Notch

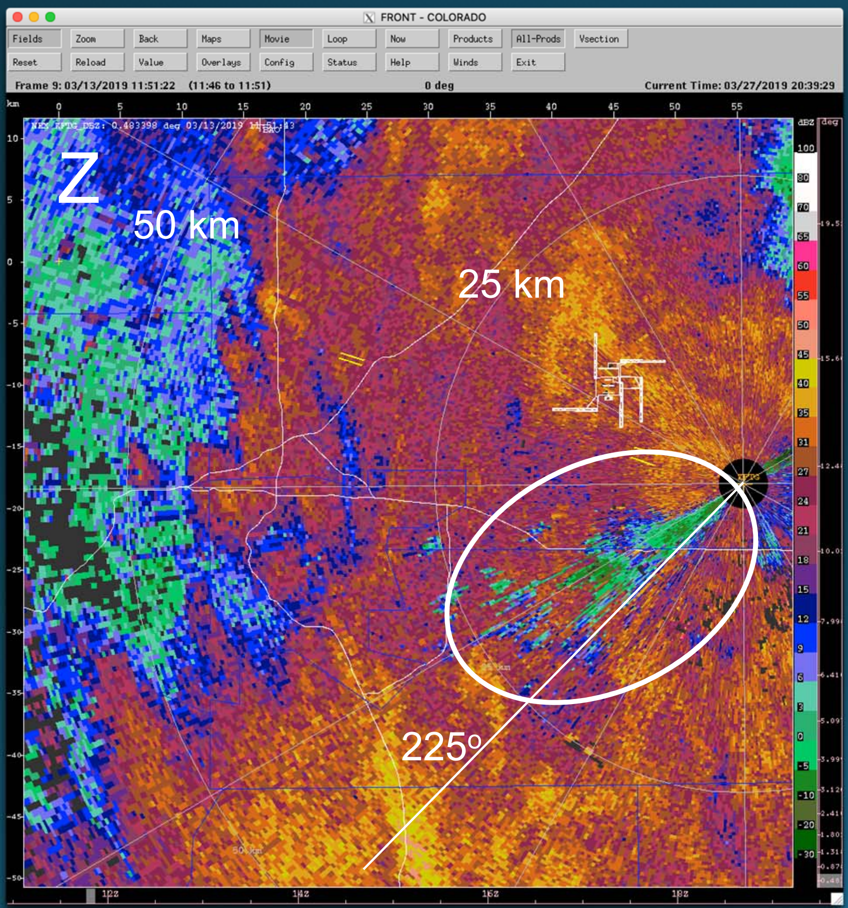
(4 blocks of 16)

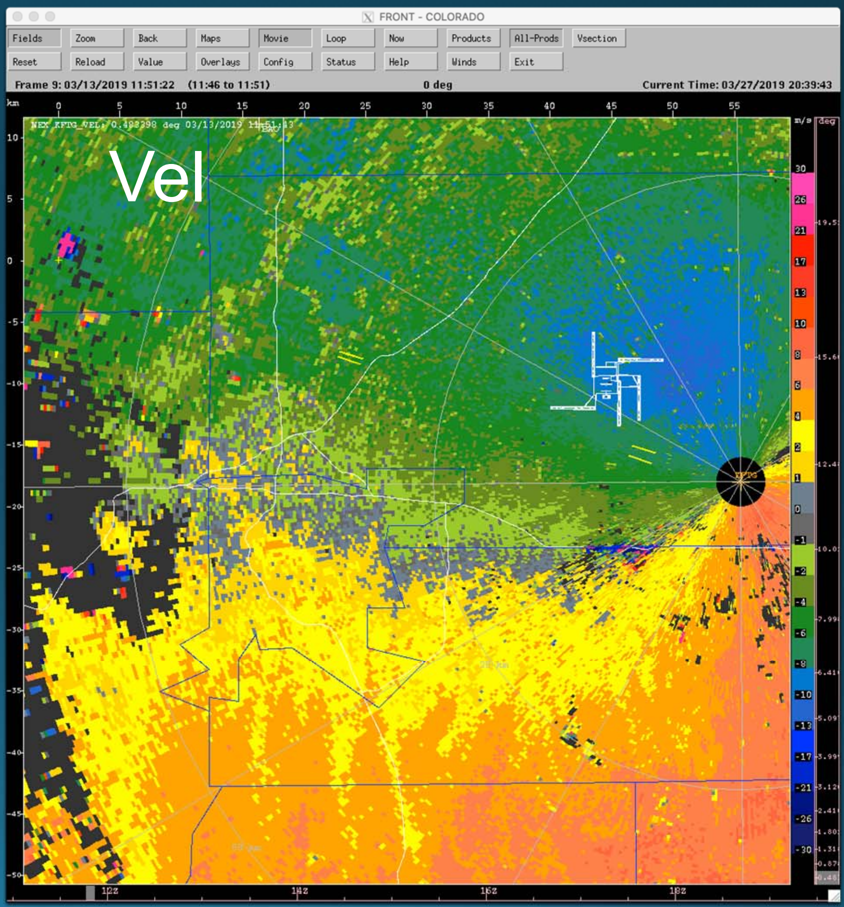




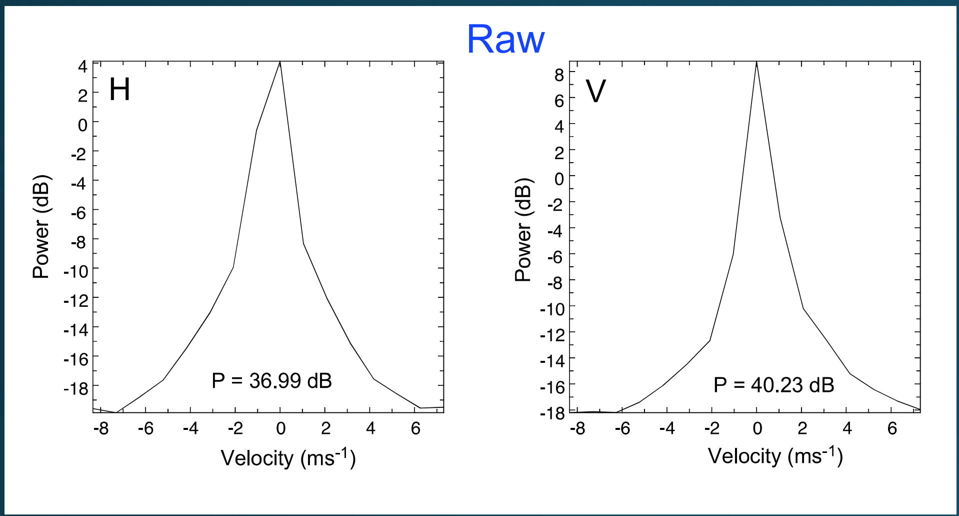
KFTG Data. “Bomb Cyclone” 13 March 2019

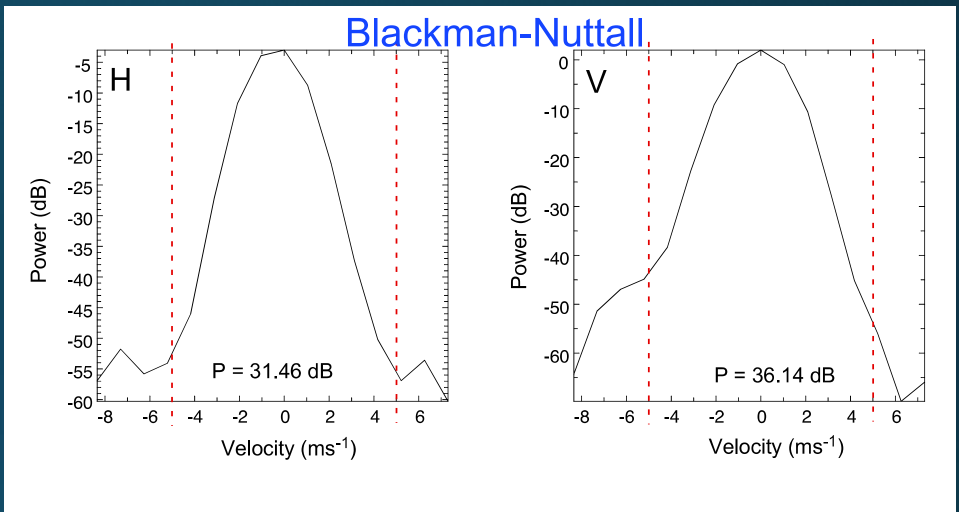
Short PRT data from VCP 212

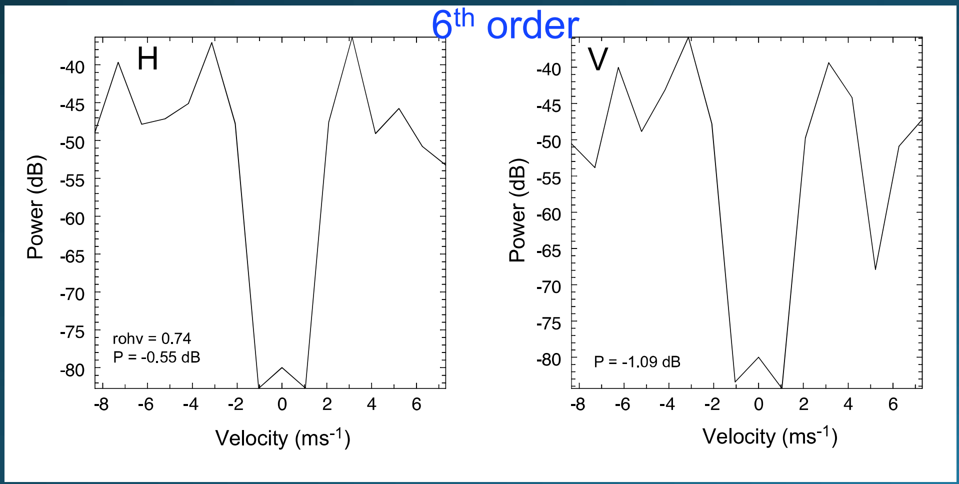


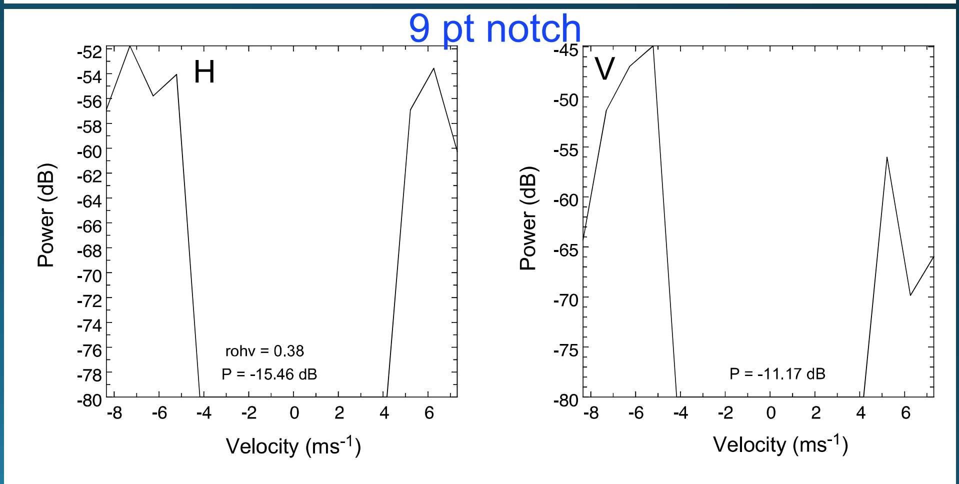


KFTG LPRT Data VCP212, 20 deg/sec, 16 points





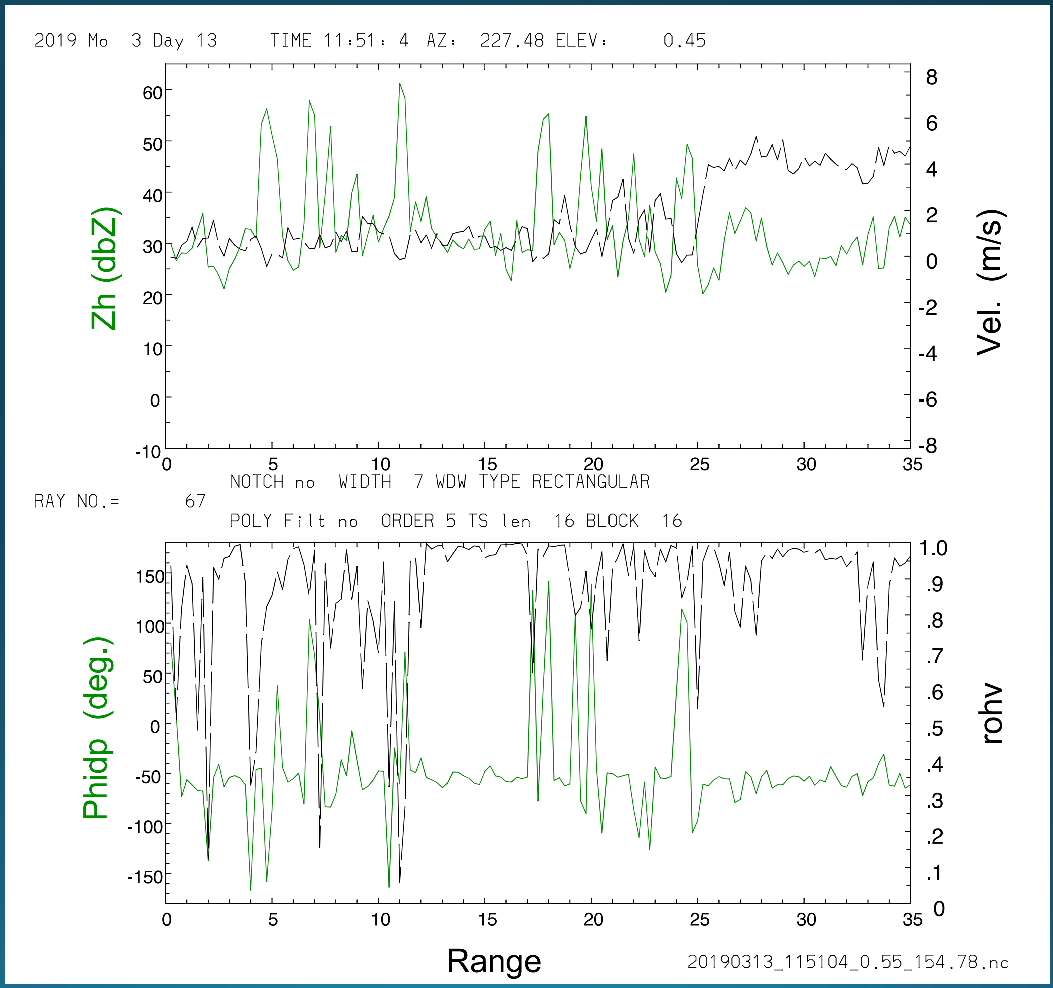




KFTG 227 Az. 0.45 elev

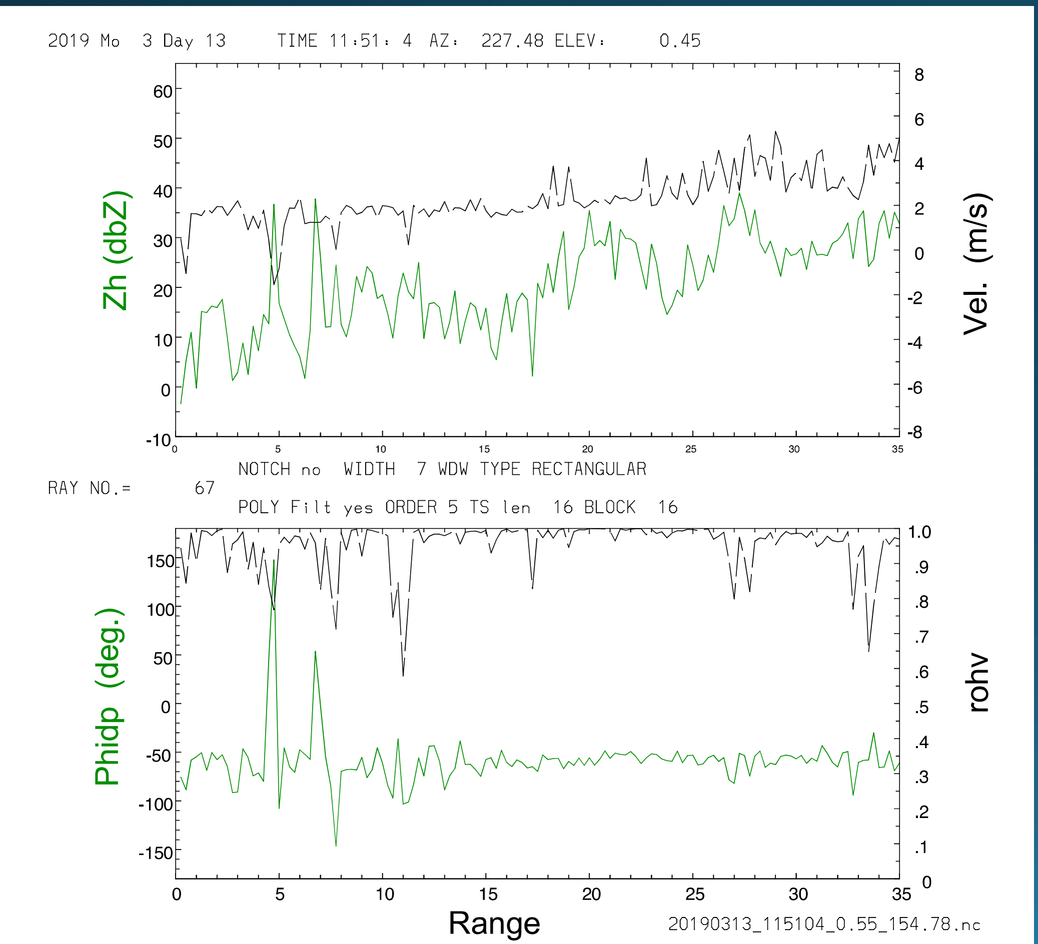
13 March 2019

Unfiltered data

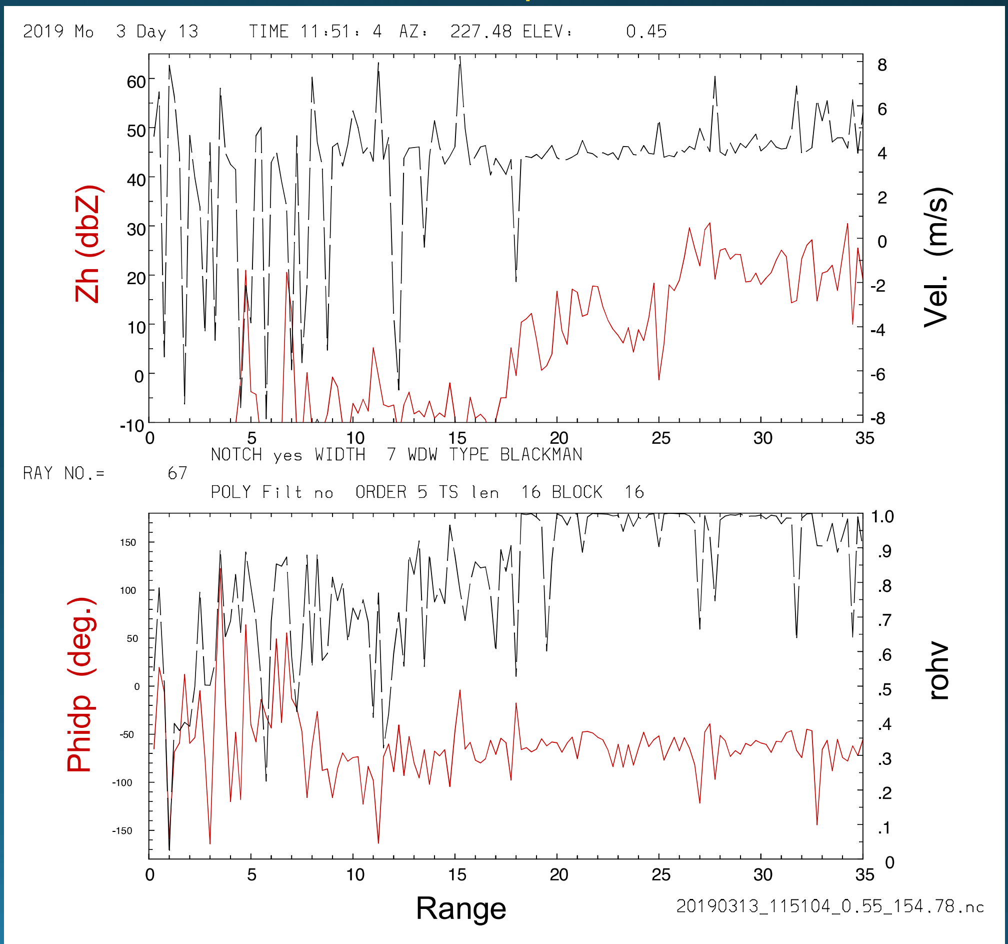


A Comparison of Regression versus Window and Notch Clutter Filters

5th order regression filter



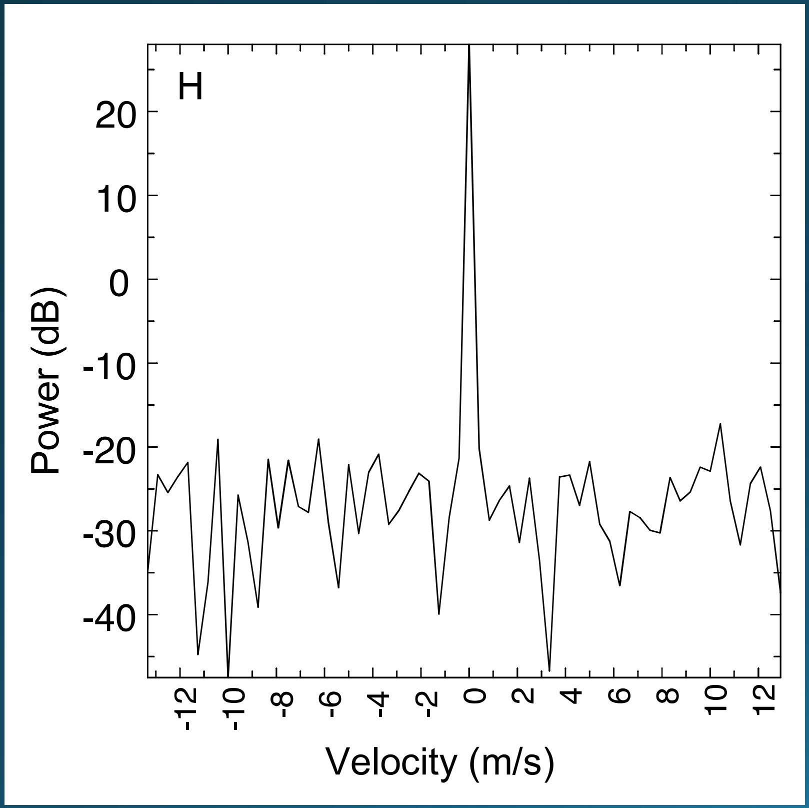
Blackman window 7 point notch



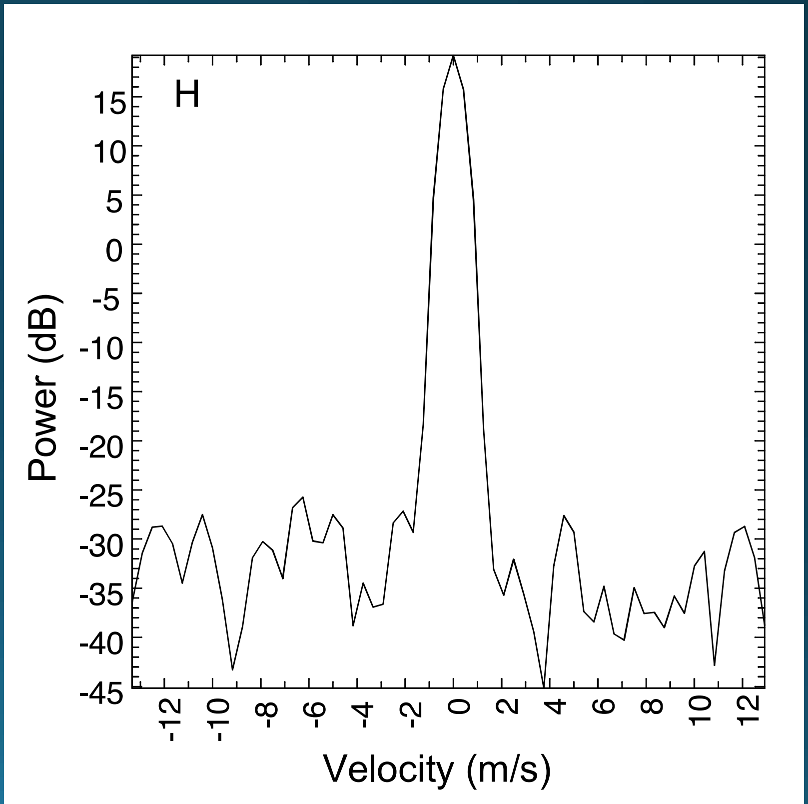
Smearing Effects of Windowing

S-Pol data

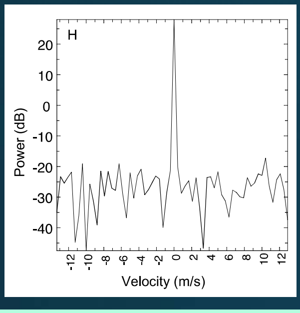
Raw data (rectangular window)



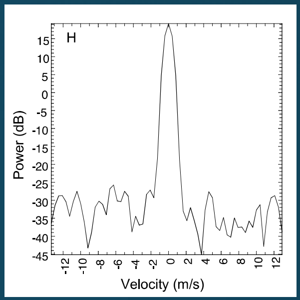
Blackman-Nuttall Window



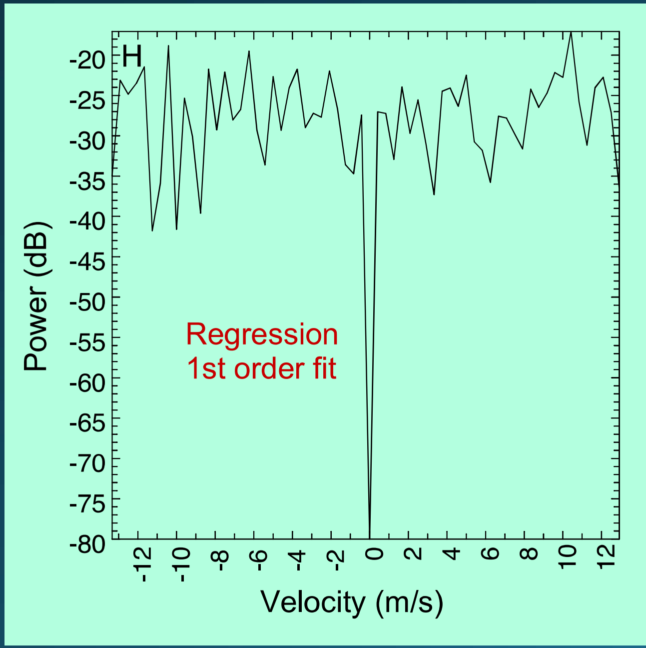
Resulting Implications for the Clutter Filter Bandwidth

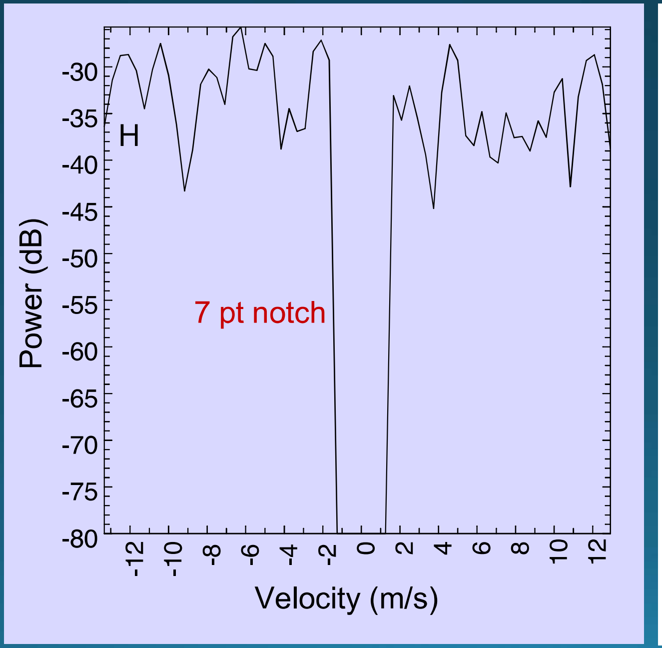


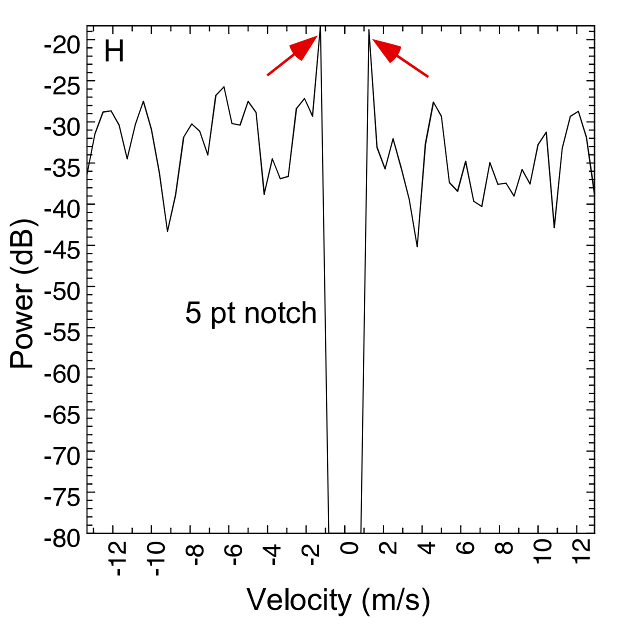
Window function spreads the clutter power so that wider bandwidth is needed



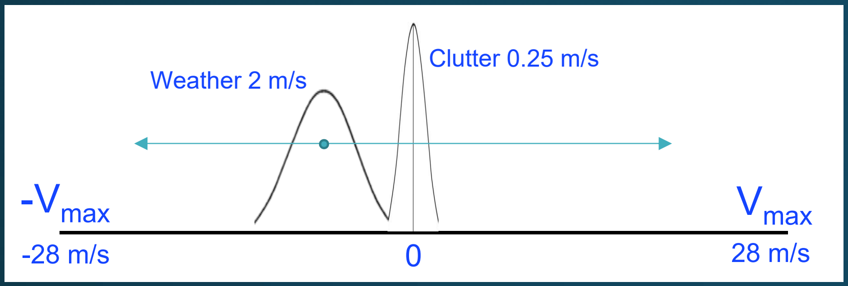
5 pt notch insufficient!!



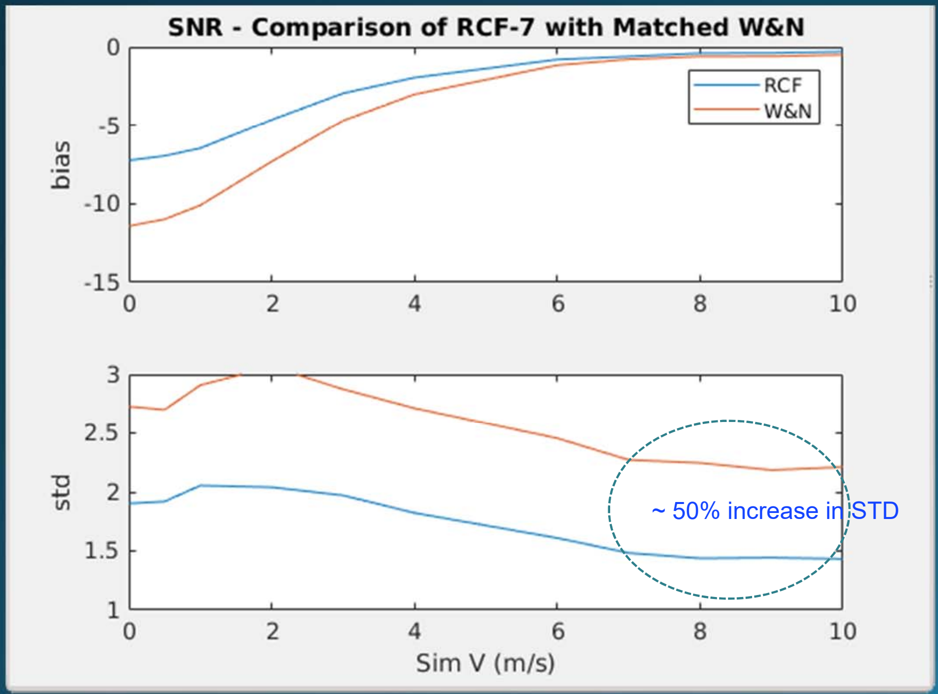


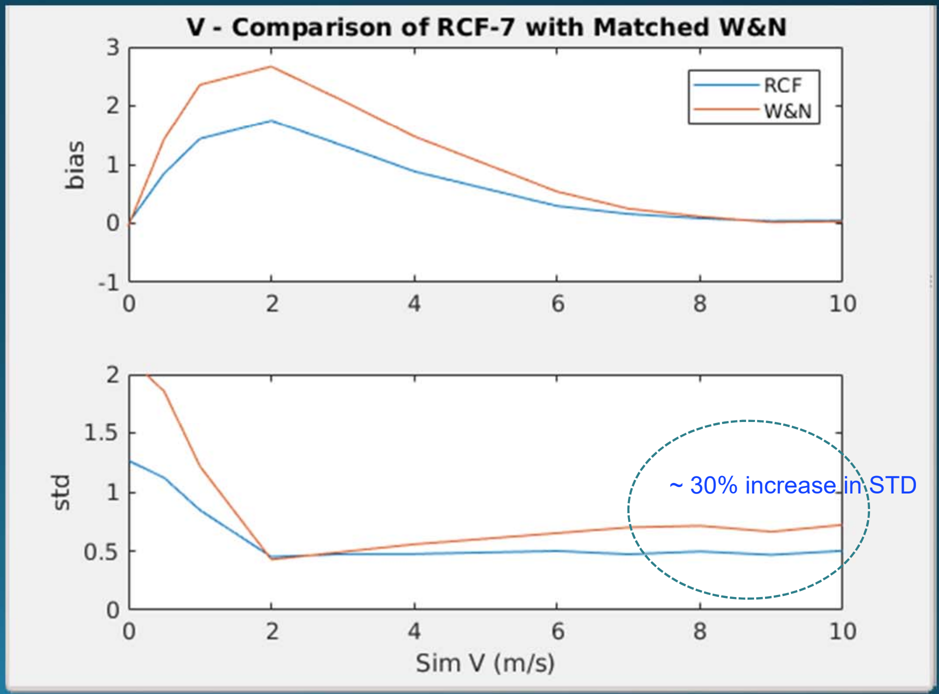


Modeling Efforts Have Begun



64 points
30 dB SNR weather
30 dB CNR clutter
Blackman Window, 9pt notch
Regression 7th order

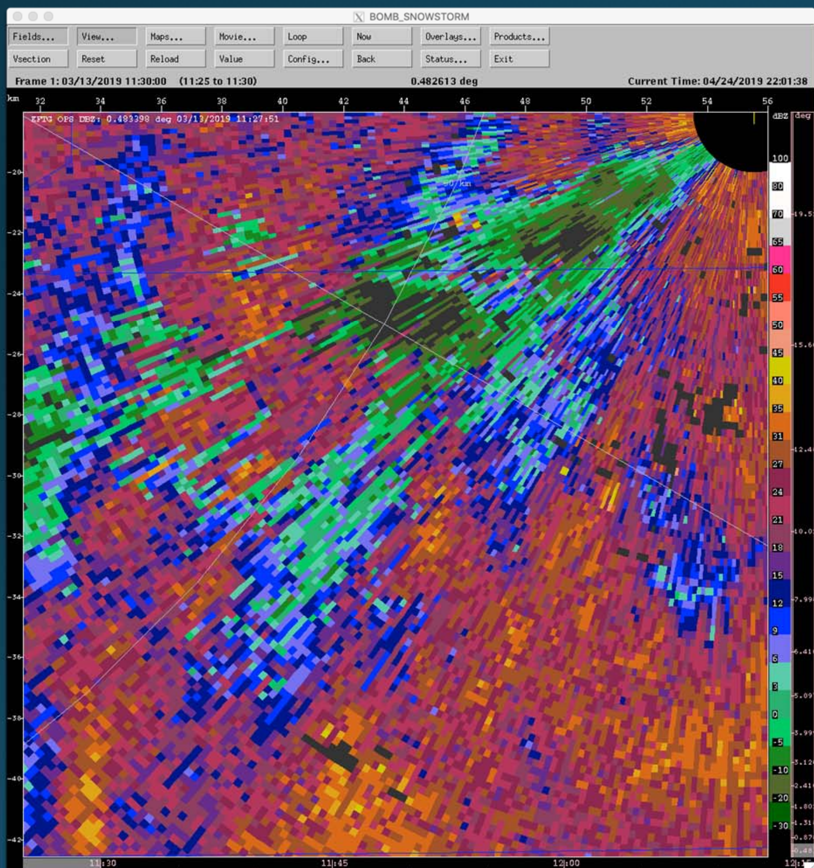




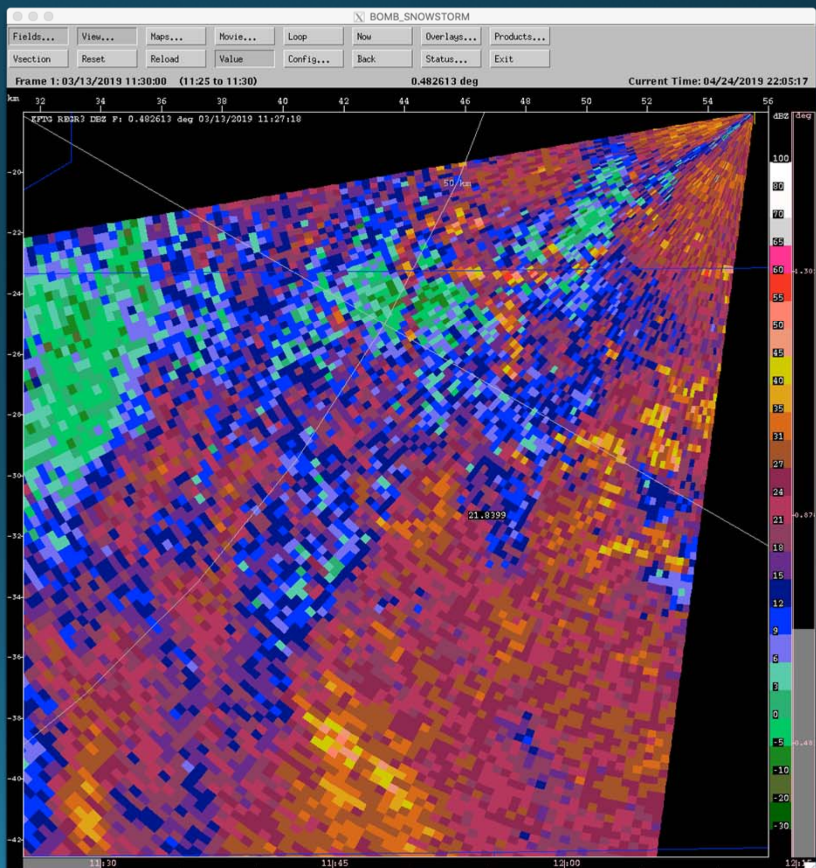
Application to Data Sets Has Begun

KFTG

Bomb Cyclone Level 2 Data



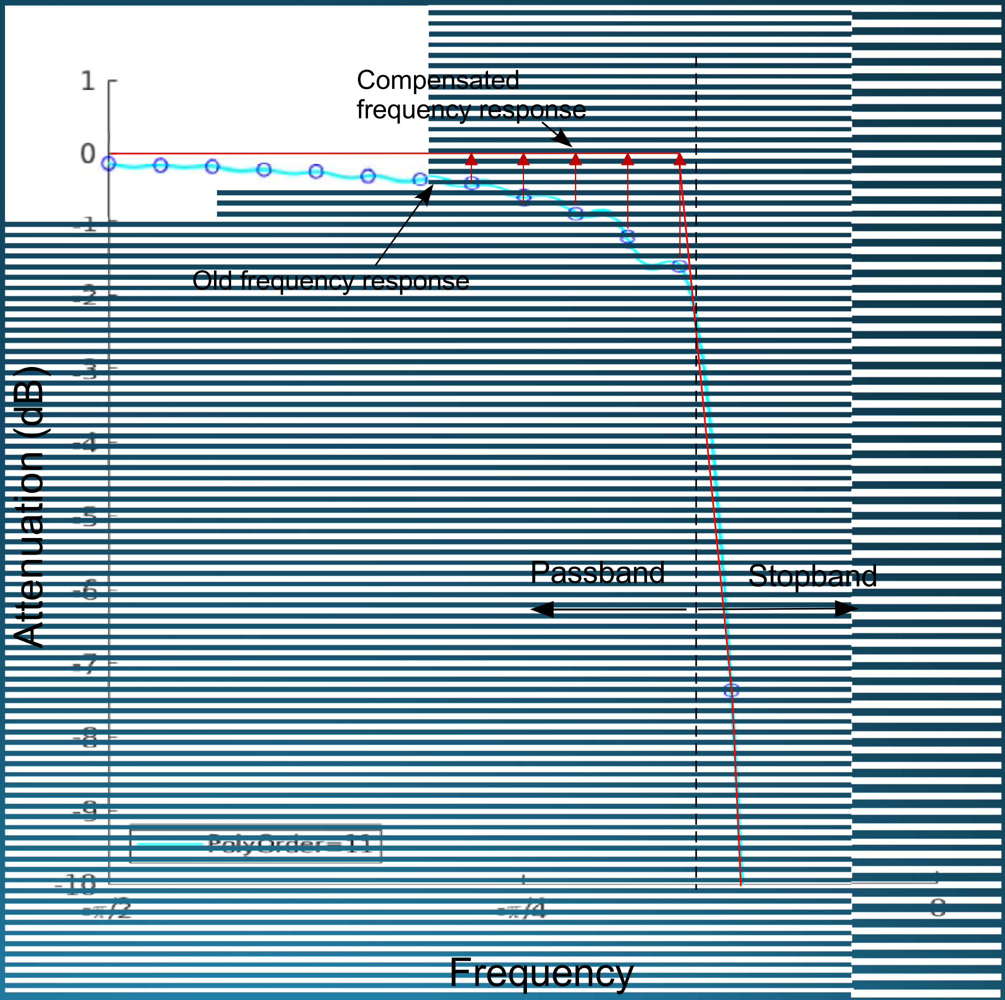
Times Series Processed with Regression Filter



Frequency Compensation

An interesting possibility

After regression filtering, FFT the resulting time series and compensate the frequencies as desired as guided by the frequency response of the regression filter.



Conclusions

- Regression and Window and Notch have equivalent clutter
- Because there is no window applied for the regression filter, *much better signal statistics can be achieved.*
- *Windowing the data, while containing “clutter leakage”, spreads the clutter (causes wider clutter bandwidth). This then requires a wider bandwidth notch as compared to regression filtering.*
- *Thus underlying weather signal is is more effectively recovered with a regression filter*
- W & N for16-point times series typically removes a very large part of the spectrum; a regression filter offers vastly superior recovery statistics.